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EXECUTIVE SUMMARY

This report provides an overview of recent Next Generation Air Transportation System (NextGen) improvements and the corresponding operational impacts that have been observed in the National Airspace System (NAS). Our objectives are to determine if the desired impacts have been achieved, quantify these impacts, and identify any unanticipated effects.

We focused on a select set of NextGen improvements that were implemented by fiscal year 2014. We included the implementations for which sufficient time has passed for a meaningful analysis to be possible and the required data was available. Our aim was to estimate the impacts of NextGen capabilities on airspace operations in a systematic and standardized way.

PERFORMANCE BASED NAVIGATION

In order to make air traffic more predictable and easier to manage, the FAA maintains a national network of routes and arrival/departure procedures. Conventional routes and procedures rely on ground-based navigational aids, while Performance Based Navigation (PBN) routes and procedures leverage technologies such as the Global Navigation Satellite System (GNSS). PBN can provide significant benefits to both the FAA and its users. For the FAA, reducing the number of conventional navigational aids will provide significant cost savings. PBN also allows more flexible, and in some cases more efficient, airspace design. For controllers and pilots, PBN provides workload reduction and safety benefits resulting from more precise navigation. In addition, for operators who have the required PBN capability, PBN provides access to the most flexible routing options during nominal operations and, in some cases, improvements in flight efficiency and increased access to airports.

This assessment focused on the impacts of three PBN initiatives:

1. Area Navigation (RNAV) Standard Terminal Arrival Routes (STAR) with Optimal Profile Descents (OPD) implemented in FY 2013,
2. RNAV Standard Instrument Departures (SID) at Atlanta and LaGuardia airports, and
3. Q-routes available NAS-wide.

RNAV STARs WITH OPDs

Starting in the terminal areas across the NAS, we investigated the typical use of the new RNAV STARs with OPDs by evaluating lateral conformance and utilization levels. Across the 11 airports with recent OPD implementations, conformance in Non-Visual Metrological Conditions (non-VMC) is higher due to fewer shortcuts, and about half of arrivals conform to at least 90 percent of the procedure distance after their joining waypoint. However, conformance and utilization levels vary by location, weather conditions, and time of day, making it difficult to develop standard definitions for their evaluation. Quite often, flights do not follow the published procedures from beginning to end, and such partial use may in fact lead to enhanced benefits because flights take advantage of shortcuts and “Direct-To” clearances when possible. As a result, although related to user benefits, utilization is not a good indicator of such benefits.

As expected, the most significant benefit from the implementation of RNAV STARs with OPDs was more efficient vertical profiles. Flights arriving from directions suitable to use the new procedures now start their descents about 7 nm (or 4 percent) closer to their destination. The proportion of flights with continuous descents increased from 9 to 16 percent, while those that level off now experience 12 percent fewer level segments, and 8 percent less time and distance in level flight. Furthermore, the remaining level segments occurred at higher altitudes. Although not directly estimated, these results also indicate fuel savings resulting from longer cruise portions of the flight and more efficient descents.

We also examined the *overall* benefits of RNAV STARs with OPDs at airports with newly-implemented procedures. On average, all arrivals to these airports experienced more efficient descents. Not only did the proportion of flights with continuous descents increase from 9 to 14 percent across all arrivals, but the arrivals with step-descents flew 6 percent shorter time and 6 percent shorter distance in level flight as well. Airports where the new procedures cover all corner posts typically experienced more significant improvement in descent efficiency. Although not as significant, departure efficiency also improved.

RNAV SIDs AT ATLANTA AND LAGUARDIA AIRPORTS

Continuing with terminal operations, we investigated impacts from Equivalent Lateral Spacing Operations (ELSO) at Atlanta. The ELSO concept takes advantage of advanced navigation capabilities to create more departure routes in the same airspace while maintaining the same spacing as conventional separation standards. Since October 2011, controllers at Atlanta Tower have been using ELSO for Runways 08R and 27R departures, resulting in shorter times of 8 to 18 seconds between successive departures, and about 1 percent higher departure throughput on the primary runways. Many of these departures now save about 6 minutes in taxi time due to significantly shorter taxi paths. Despite greater reliance on the primary runways, average times in departure queues have also decreased by over a minute. Furthermore, in east operations, ELSO enabled a better segregation of departures headed in different directions between the north and south sides of the airport.

Our last terminal airspace assessment was of the TNNIS RNAV SID from New York LaGuardia (LGA). This new procedure enables simultaneous departures from LGA Runway 13 and arrivals to New York Kennedy (JFK) Runway 22R, which was not possible in the past. The TNNIS SID is an example of PBN alleviating constraints imposed on one airport by another nearby airport. Not only is JFK now able to use its preferred arrival runway configuration more often, it is also able to use high-end Airport Arrival Rates (AARs) more often. As a result, when LGA uses Runway 13 for departures, the arrival throughput at JFK is over 2 percent higher on average in non-VMC, and exhibits significantly less variance in VMC. Both of these outcomes contribute to smoother and more efficient arrival flows at JFK.

Q-ROUTES

Finally, we examined PBN impacts in the en route airspace. By the end of FY 2013, 94 Q-routes were available across the NAS. Each of the routes was used to some extent. However, about a third of the routes accounted for 95 percent of all flight plan requests. Although only about 3 percent of flights request to fly Q-routes on a daily basis, the use is much higher between airports where the routes are both close to the direct path between the origin and destination, and efficiently connected with corresponding SIDs and STARs. Compared to other flights between the same airport pairs, those that request Q-routes experience 14 nm shorter excess distance and two minutes less arrival delay on average.

TIME BASED FLOW MANAGEMENT

To regulate the air traffic flows throughout the NAS, FAA traffic managers employ a number of techniques called Traffic Management Initiatives (TMI). Since the early days of air traffic management, TMIs have effectively lowered the rate of air traffic during periods when demand was expected to exceed capacity. Built on the foundation of Traffic Management Advisor, Time Based Flow Management (TBFM) offers a more efficient alternative by moving the focus from control to management of traffic flows.

TBFM capitalizes on four time-based metering techniques:

- Arrival Management/Situational Awareness – monitors projected runway demand and arrival flows
- Airborne Metering – schedules runway assignments and landing times, and allocates airborne delays
- Departure Scheduling – adjusts departure times by considering restrictions at their destinations
- En Route Departure Capability (EDC) – adjusts departure times as needed for their efficient merging into the overhead, en route traffic

TBFM automation is deployed at 78 facilities across the NAS, including 20 en route, 25 terminal and 33 tower facilities, and is currently used to manage arrival flows to 24 of the Core 30 airports. The use of TBFM to manage arrival flows varies across facilities and airports. One common pattern is regular use of Departure Scheduling or Airborne Metering at certain times of day. Another is to use Departure Scheduling alone and, for some airports, to include Airborne Metering as needed. For some airports with decreasing volume the use of Airborne Metering has been declining.

At airports that regularly use only Departure Scheduling, arrivals managed by this function of TBFM experienced around one minute less arrival delay. In addition, the variability of their delay was lower.

At facilities that regularly use Airborne Metering, we observed a difference of 8 to 10 minutes between the average arrival delays of metered flights and those subject to Miles-In-Trail restrictions alone. It is unclear how much of this difference can be attributed to TBFM because a large portion of it occurs on the ground prior to push-back. However, metered flights also experience fewer extreme airborne delays and less variation in airborne delay, including significantly less holding and vectoring before entering the arrival Center.

AUTOMATED TERMINAL PROXIMITY ALERT

Integral to a terminal automation system, Automated Terminal Proximity Alert (ATPA) assists controllers by displaying spacing that aircraft are projected to have on their final approach course and warns of predicted loss of separation.

Although ATPA improves controllers' awareness, how and if they use the tool is hard to discern. It's an advisory tool and controllers can choose whether to view its projections and warnings. Because a consistent record of these settings is not available, our assessment focused on the differences in arrival spacing and go-arounds before and after ATPA became operationally available, irrespective of its use.

Human factors studies showed significant differences in ATPA use across facilities, and our most recent empirical assessment discerned no significant or consistent changes in arrival spacing and go-arounds. However, despite this inconclusive quantitative assessment, ATPA has received highly favorable ratings by controllers. At four facilities that participated in post-implementation human factors assessments, a majority of the controllers reported that they regularly used ATPA because it was easy to use and beneficial. ATPA frees controllers from having to manually invoke software features to display spacing information. Controllers report that having this information available automatically improves their situational awareness as they manage arrivals on final approach. This tool is thus likely to facilitate the introduction of new wake turbulence mitigation concepts and to enhance their effectiveness.

RECATEGORIZATION OF WAKE TURBULENCE SEPARATION CATEGORIES

Controllers must maintain a minimum separation distance between aircraft on final approach to ensure that the wake of each aircraft does not upset the aircraft behind. These separation standards vary depending on the aircraft types involved. Following over a decade of research conducted by the FAA, NASA, EUROCONTROL, ICAO, and their industry partners, the FAA developed new aircraft classes and spacing criteria based on aircraft wingspan, weight and ability to withstand a wake encounter. Compared to the traditional categorization, the revised wake Recategorization (RECAT) results in less variation of weight, speed and wake characteristics among the aircraft belonging to the same category; as a result, separation standards can now be safely reduced for many aircraft pair combinations. Controllers at Louisville International Airport (SDF) began to use the new wake categories in November 2013. Our analysis revealed an increase in airport capacity and throughput and reduced taxi-out times, with the most significant improvements observed during peak periods and Instrument Meteorological Conditions (IMC).

Since the adoption of RECAT at SDF, average AARs have increased by 3 percent during IMC, and average Airport Departure Rates by 6 percent. While maximum rates have not increased, the facility used high-end rates more often during IMC. Rates of 45 arrivals per hour or higher were used 18 percent more often, and 45 departures per hour or higher 25 percent more often. Even though traffic levels at SDF remained the same, airport throughput increased 4 percent during peak arrival and 5 percent during peak departure periods, indicating tighter aircraft sequences and improved airport efficiency. This further led to a 1.7 minute reduction in taxi-out times during peak departure periods, a 24 percent decrease.

DEPENDENT INSTRUMENT APPROACHES TO CLOSELY SPACED PARALLEL RUNWAYS

Prior to 2008, the FAA prohibited the use of dependent instrument approaches for parallel runways with centerline spacing less than 2,500 ft. In November of that year, the FAA first published Order 7110.308, allowing dependent instrument approaches to specific parallel runways with centerline spacing less than 2,500 ft., known as Closely Spaced Parallel Runways (CSPR). In October 2012, we updated the Order to allow dependent instrument approaches for additional airports and runway pairs, including Runways 28L/R at San Francisco (SFO).

Because of a runway construction project during which instrument landing system 28L was out of service, operational use of dependent instrument approaches at SFO did not start until September 2013. The use of dependent instrument approaches to CSPRs enabled effective capacity gains at SFO during operating conditions when only single runway approaches had been possible in the past. During the first four months after initiation of dependent approaches, average arrival and departure throughput each increased by 8 percent, despite only a 4 percent increase in overall demand. The facility set high-end arrival and departure rates 11 percent more frequently, resulting in increased effective capacity and throughput and reduced delays.

PERFORMANCE BASED NAVIGATION

PERFORMANCE BASED NAVIGATION

Performance Based Navigation (PBN) refers to navigation using GPS and other Area Navigation (RNAV) technologies rather than conventional, terrestrial navigational aids (NAVAID). Currently, the FAA operates almost 1,000 federally owned VHF Omni-directional Range (VOR) NAVAIDs, most of which are over 30 years old. PBN provides an opportunity to reduce this aging infrastructure and deliver the same, if not improved, quality of service. Required Navigation Performance (RNP) is an additional aspect of PBN that incorporates onboard monitoring and alerting capabilities, and delivers the highest accuracy of navigation.

The FAA has started working on the requirements for the reduced network of VOR NAVAIDs, called Minimum Operational Network (MON), and expects to begin NAVAID decommissioning[1] in 2015 [1]. The VOR MON will enable basic navigation for users who choose not to equip with GNSS, and will serve as a backup capability in the event of a GPS outage. For the FAA, MON will provide significant cost savings by reducing required flight checks and NAVAID maintenance. For those operators who have the required capability, PBN will provide access to the most flexible routing options during nominal[2] operations. In many cases, this can translate to improvements in flight efficiency and increased access to airports.

The FAA continues to fine-tune its National Route Structure Plan (NRSP) under the guiding principle of "structure where structure is necessary and point-to-point where it is not." By capitalizing on both MON and PBN, the NRSP considers traffic demand, airspace access and utilization, air traffic control (ATC) task complexity and user operational efficiencies to deliver a national network of Air Traffic Service routes and point-to-point navigation [2]. As a result, it enables more flexible airspace design and user navigation as well as more dynamic air traffic management and optimized use of airspace, improving system and user efficiency.

As we transition to PBN and evolve our NAVAID network, we will maintain a transitional network of VORs to support mixed capability operations, providing time for users to acquire the required performance capability. We also continue to maintain conventional procedures to provide uninterrupted services for all aircraft and operators.

PBN PROCEDURES AND ROUTES

In terminal areas across the National Airspace System (NAS), aircraft operating under Instrument Flight Rules (IFR) fly conventional or RNAV Standard Instrument Departure (SID) and Standard Terminal Arrival Route (STAR) procedures while transitioning between an airport and an airway. SIDs and STARs are published routes that aid controllers with issuing departure and arrival clearances. They are designed to support typical flows in the terminal area, while avoiding obstacles, Special Use Airspace (SUA) and conflicting traffic flows. Unlike PBN procedures, conventional procedures are constrained by the availability and proximity of NAVAIDs.

In en route airspace, aircraft fly conventional and RNAV routes as well: Victor and T routes in low-altitude, and Jet and Q routes in high-altitude airspace[3]. These routes are designed to support typical flows during the cruise phase of flight, while avoiding SUA and conflicting traffic flows. Again, conventional routes are constrained by the availability and proximity of NAVAIDs.

Due to significant differences in the nature of the terminal and en route operations, the operational performance impacts of PBN in each domain are presented separately in the sections that follow.

OPERATIONAL PERFORMANCE ASSESSMENT OF RNAV SIDs AND STARs

This section of our assessment focuses on impacts of all RNAV STARs with Optimized Profile Descents (OPD) implemented in FY 2013, and on RNAV SIDs implemented at Atlanta and LaGuardia airports to alleviate traffic flow interaction.

TERMINAL PROCEDURE INVENTORY AND EQUIPAGE

By the end of 2013, the FAA had implemented over 430 RNAV SIDs and 250 RNAV STARs, while maintaining nearly 500 conventional SIDs and 330 conventional STARs [3]. RNAV procedures now account for over 40 percent of all SIDs and STARs in the NAS (Fig. 1-1).

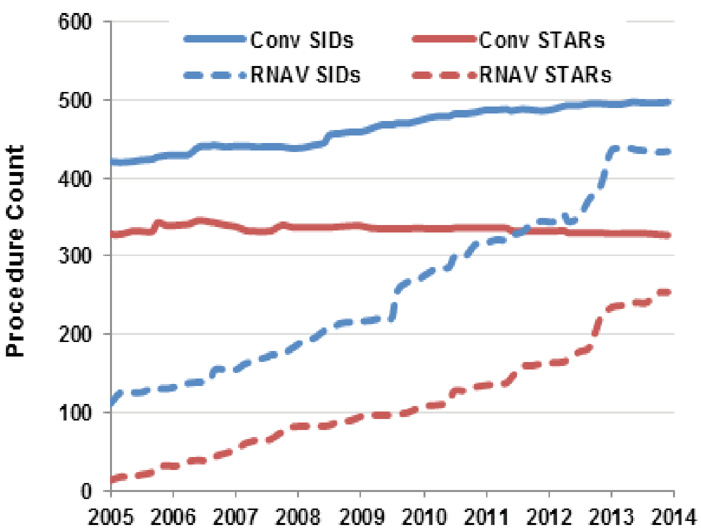

Figure 1-1 – Availability of SIDs and STARs in the NAS

About 27 percent of the conventional procedures and 40 percent of the RNAV terminal procedures serve flights at the top 77 airports in the NAS, also known as the 77 Aviation System Performance Metrics (ASPM) airports. About 6 percent of these airports have no conventional procedures and 36 percent no RNAV procedures. However, airports that do need terminal procedures have four procedures of each type on average, and up to 14 conventional and 18 RNAV SIDs and 14 conventional and 17 RNAV STARs. These statistics clearly demonstrate that the FAA implements procedures only where it needs structure to help controllers manage traffic flows and help aircraft navigate around terrain, obstacles and restricted areas. Many terminal areas do not have problems with congestion, challenging flow interactions or complex airspace design restrictions.

As a result, their need for terminal procedures is limited. The FAA established a special team of subject matter experts tasked with reviewing procedures and recommending changes with a goal of improving the inventory to better serve the needs of both users and service providers.

Airports that operate in proximity to each other often share many of the same terminal procedures: about 6 percent of RNAV SIDs, 17 percent of conventional SIDs, 34 percent of RNAV STARs and almost 60 percent of conventional STARs serve multiple airports. In addition, about 47 percent of RNAV STARs and 10 percent of RNAV SIDs represent joint use, also known as overlays, of the conventional procedures (Fig. 1-2). Under Congressional guidance, the FAA is now working to minimize the need for joint-use procedures while ensuring service provision to all of its users, irrespective of their navigational capabilities. The FAA manages terminal network structure at a system level. First, components that depend on availability and layout of the ground-based NAVAIDs are shared when possible. Second, to capitalize on the routing structure that has already been optimized, and facilitate simultaneous operations of flights with mixed performance capabilities, conventional and RNAV components overlap when beneficial.

In summary, even though removing dependence on ground-based NAVAIDs results in more flexible airspace and procedure design, a distinct RNAV procedure will be implemented only when airspace design restrictions can be improved by the higher navigational accuracy of RNAV arrivals and departures. For instance, RNAV procedures can be placed closer to an obstacle, terrain or restricted airspace to provide a shorter path through terminal airspace. RNAV procedures can be introduced to deconflict flows, which is especially important in Metroplex environments, or to optimize location of traffic merge points to provide sufficient room for speed control and vectoring and to facilitate aircraft sequencing and merging.

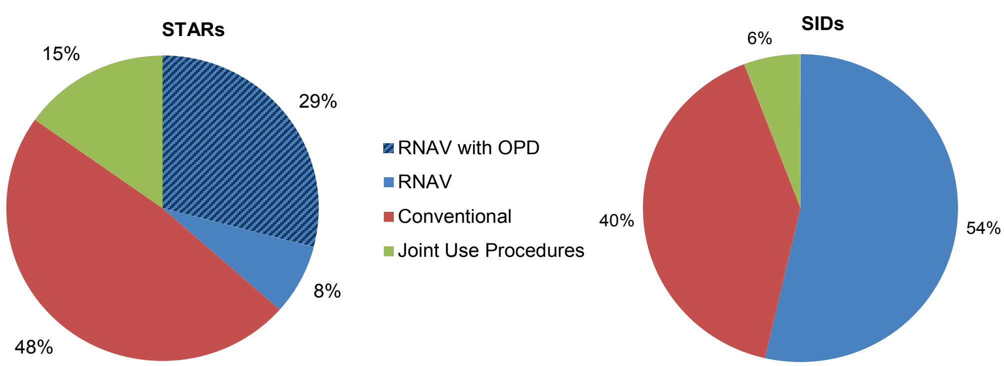

Figure 1-2 – Terminal Procedure Inventory as of December 2013

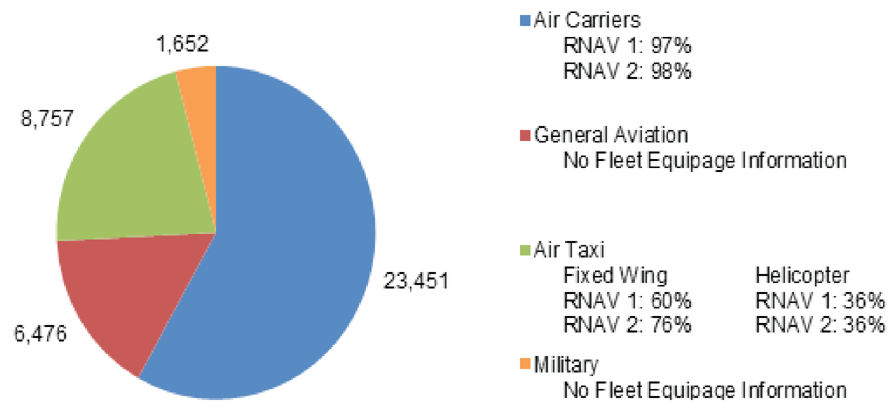

Figure 1-3 – Average Daily IFR Flights in FY2013
and RNAV Capability by Operator Type

Almost 90 percent of the domestic commercial fleet is RNAV capable; however, the variation in RNAV capability among different operators is quite significant (Fig. 1-3). For instance, 97 and 98 percent of the Part 121 operator fleet has approval to fly RNAV 1 and RNAV 2, respectively; these aircraft account for almost 60 percent of all air traffic in the NAS [4-5]. However, RNAV capability of the air taxi fleet is significantly lower: 60 percent of the fixed-wing fleet is RNAV 1 capable and 76 percent is RNAV 2 capable, as is only 36 percent of the helicopter fleet (both RNAV 1 and RNAV 2). Air taxi operations account for 22 percent of air traffic in the NAS. Information about RNAV capability among the general aviation and military fleets is not readily available at this time, but these aircraft account for just 16 and 4 percent of operations under positive air traffic control, respectively.

Primary Airport	Count
Albuquerque International (ABQ)	5
Atlanta International (ATL)	3
Nashville International (BNA)	4
Charlotte-Douglas Int. (CLT)	1
Denver International (DEN)	16
Chicago Midway Int. (MDW)	1
Portland International (PDX)	1
Raleigh/Durham Int. (RDU)	3
Seattle-Tacoma Int. (SEA)	2
Lambert St Louis Int. (STL)	4
Teterboro (TEB)	1

Table 1-1 – Inventory of RNAV STARs With OPDs
Published in FY 2013

OPERATIONAL PERFORMANCE IMPACTS OF RNAV STARs WITH OPDs

In FY 2013, the FAA published 41 RNAV STARs serving 11 ASPM77 airports that facilitate OPDs. FAA's PBN Policy and Support group adopted the following criteria to categorize an RNAV STAR as an OPD:

1. The procedure has coded altitudes.
2. ATC can use "descend via" phraseology with the procedure.
3. The procedure can contain an "expect" altitude with other, coded altitudes. The expect altitude can be "cleared" by ATC issuing a restriction for the corresponding waypoint.
4. The procedure should not contain any airframe-specific instructions, such as '*jets cross at xxx, turboprops cross at xxx*'.

The number of recently published OPDs varies from one airport to another (Table 1-1). At Nashville International (BNA), the new OPDs cover all four corner posts, while a single new OPD serves arrivals over only one of the corner posts at Portland International (PDX). Denver International's (DEN) newly implemented arrival procedures support several different airport configurations and often overlap one another, resulting in 16 new RNAV STARs with OPDs.

Methodology

The purpose of our analysis is to examine any differences in flow-based performance outcomes associated with the implementation of RNAV STARs with OPDs. Therefore, our analysis compares all flights that were in position to use the new OPDs to the flights arriving via the same flows prior to implementation. The remainder of this section describes the methodology applied.

We used the PBN Dashboard to identify flights that were likely flying the new OPD procedures, and categorized them into key arrival flows based on where they entered a 250 nautical mile (nm) ring around the arrival airport. To remove data inconsistencies and potentially anomalous behavior, we focused on the flights that originated outside the 250 nm ring and the middle 90 percent of arrivals in each flow (Fig. 1-4). At airports that have more than one OPD serving the same corner post, such as DEN, we combined the overlapping flows, which resulted in 28 key traffic flows defined by all of the FY 2013 implementations.

To determine common behavior and conformance characteristics across a wide range of locations, we also investigated conformance to RNAV STARs with OPDs. Note that this part of our analysis was separate from the operational impact investigation – we did not consider conformance level when assessing performance, but only direction of flight and key flows that were in position to fly the new OPDs.

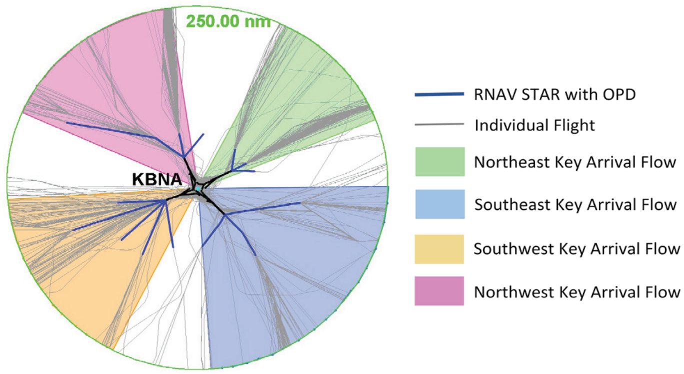

Figure 1-4 – RNAV STARs With OPDs and Key Traffic Flows at BNA

For any procedure, the implementation date may be different from the date it was first flown. We evaluated performance of key flows in position to use the new OPDs from the dates of their first use through end of FY 2013 (post-implementation period), and compared it to that of the same flows and start use-date back to the beginning of FY 2012 (pre-implementation period). In total, more than 1.6 million flights were included in our analysis.

We investigated performance by key traffic flow, and aggregated them to airport and NAS-wide levels. We also considered weather condition (VMC and Non-VMC), and focused on vertical profile efficiency indicators, including number of level segments, time and distance in level flight, time weighted altitude[4] (TWA), and proportion of flights flying continuous descents[5]. Finally, we evaluated time and distance within 250 nm of the arrival airport, and time and distance below Top of Descent (TOD) to examine other potential impacts related to flight efficiency.

Changes in Performance Outcomes of Flights in Key Arrival Flows

We observed two significant impacts after implementation of OPDs that resulted in improved vertical profiles of arrivals. First, aircraft in key arrival flows are more likely to fly continuous descents, indicated by an increase in proportion of flights executing continuous descents from 9 to 16 percent (Table 1-2). Second, step-descent profiles are now more efficient now as well, indicated by 12 percent fewer level segments, 8 percent less time and 8 percent shorter distance in level flight. In addition, TWA of the arrivals that flew step-descents increased by 6 percent, indicating that the remaining level segments are now flown at higher altitudes.

Across all arrivals in key flows, aircraft on average flew 17 percent fewer level segments, and spent 14 percent less time and 13 percent shorter distance in level flight after OPD implementation. In Non-VMC, the average changes were less substantial, likely resulting from a lower probability of receiving a “descend via” clearance.

During typical operating hours (between 6 AM and 11 PM local time), the changes in vertical efficiency are slightly better than those observed over all hours. However, flights arriving between 11 PM and 6 AM local time experience more modest improvements in performance, such as an 8 percent reduction in level segments and a 2 percent reduction in time in level flight. Since the flights arriving in the middle of the night already had more flexibility to take shortcuts and were more likely to fly continuous descents, there was simply less room for improvement for these flights.

Table 1-3 – Time and Distance for Flights in Key Arrival Flows

Note: The value outside the parentheses represents an average outcome, while the value inside the parentheses the change compared to before implementation. Green shading indicates improvement.

	Below Top of Descent		Within 250 nm	
Weather	Time (min)	Distance (min)	Time (min)	Distance (min)
VMC	28.1 (-3%)	158.2 (-4%)	44.2 (0%)	270.1 (0%)
Non-VMC	31.4 (-3%)	171.8 (-4%)	46.7 (-1%)	277.2 (0%)
All	28.6 (-4%)	160.2 (-4%)	44.6 (0%)	271.3 (0%)

Time and distance within 250 nm of each airport did not significantly change after implementation of OPDs (Table 1-3). However, due to the improved vertical profiles, TOD is now about 4 percent closer to the airport on average, implying additional benefits in fuel savings due to a longer en route portion of the flight.

As expected, performance impacts vary by airport and are generally greater and more significant at locations where the new OPDs can be used by a higher proportion of arrivals (Fig. 1-5). For example, at BNA the new OPDs cover all of the four corner posts, and aircraft that flew step-descents experienced a reduction of 21 percent in number of level segments, 18 percent in time in level flight, and 17 percent in distance in level flight. After implementation of the OPDs, TWA increased 14 percent, and the proportion of arrivals flying continuous descents more than tripled.

Some of the new RNAV STARs with OPDs did not facilitate improvements

Table 1-2 – Vertical Profile Performance Outcome Comparisons for Flights in Key Arrival Flows

Note: The value outside the parentheses represents the average outcome, after implementation while the value inside the parentheses represents the percent change compared to before implementation. Green shading indicates improvement.

Weather Conditions	Proportion of Flights	Number of Level Segments	Time in Level Flight (min)	Distance in Level Flight (nm)	TWA (FEET)	Flights with Continuous Descent	
						Before	After
VMC	83%	2.2 (-12%)	6.2 (-8%)	35.0 (-8%)	17,000 (6%)	10%	17%
Non-VMC	17%	2.7 (-9%)	8.0 (-7%)	42.4 (-5%)	14,900 (8%)	7%	11%
All	100%	2.3 (-12%)	6.5 (-8%)	36.1 (-8%)	16,600 (6%)	9%	16%

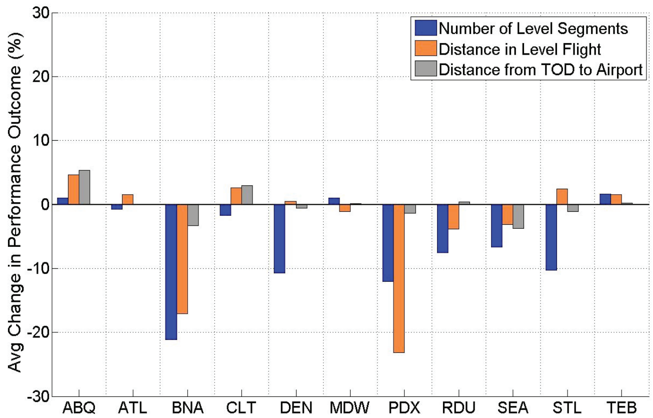

Figure 1-5 – Average Changes in Vertical Efficiency Outcomes for Flights on Key OPD Arrival Flows

in vertical efficiency. For instance, at ABQ, it is possible that the new RNAV STARs reduced the flexibility of the conventional procedures, resulting in less optimal trajectories at this relatively low traffic airport. Since the RNAV STARs with OPDs implemented at ATL, CLT, MDW, and TEB do not cover all arrival corner posts, the vertical efficiency benefits associated with the key arrival flows may have been diminished due to merging and coordination with non-OPD flows in these highly congested airspaces.

Changes in Performance Outcomes for All Flights at Airports with OPDs

Although the key arrival flows using the new RNAV STARs with OPDs will likely accumulate the most benefits, the new procedures could also benefit the airport by making the airspace more efficient. On average, vertical efficiency of flights has improved across all of the 11 airports (Table 1-4). Airports with OPDs serving a majority of the arrival traffic, such as BNA, DEN, STL, and RDU, experience the largest benefit in vertical profile performance outcomes. The exception is ABQ as discussed in the previous section. While average Time and Distance within 250 nm of the airport has not significantly changed across the locations, the same outcomes have not significantly increased at any of the locations, but have decreased at PDX and SEA[6].

In addition, departures exhibited more efficient vertical profiles after implementation of the OPDs. This improvement was predominantly driven by an increase in the proportion of flights executing continuous ascents (Table 1-5). Although vertical profiles of the departures with step-ascents are slightly less efficient now, on average departures now exhibit 9 percent fewer level segments, 8 percent less in time and 7 percent shorter distance in level flight.

Procedure Conformance

The analysis and findings discussed in the previous section included all flights in the key flows served by the new OPDs, irrespective of their conformance to the published procedures. It is important to understand how STARs are used in addition to the benefits they incur. At many locations, flights partially conform to procedures as opposed to flying them entirely from beginning to end. Flights often join procedures at waypoints close to the airport, or are given shortcuts that allow for more efficient lateral paths. However, benefits are not directly proportional to conformance level, and partial use can often result in even higher benefits. Therefore, procedure conformance and utilization are typically not good indicators of flight efficiency benefits, but are necessary to consider to fully understand performance impacts and benefits.

This section describes lateral procedure conformance. This is determined by how much an arrival flew over the procedure from the first waypoint it was cleared to join to the end of the common route or the most relevant runway transition[7]. In VMC, about half of all arrivals joined the new OPDs within 105 nm of the airport, and about 10 percent of arrivals joined them further than 200 nm from the airport (Fig. 1-6). In addition, about one-third of all flights conform up to 70 percent of the distance after the joining waypoint, and almost 45 percent of arrivals conform for more than 90 percent. Across the 11 airports with recent OPD implementations, conformance in Non-VMC is higher due to fewer shortcuts, resulting in an additional 5 percent of flights with 90 percent or higher conformance. Moreover, 35 percent of flights fully conform from the joining waypoint onward in non-VMC, compared to about 25 percent in VMC.

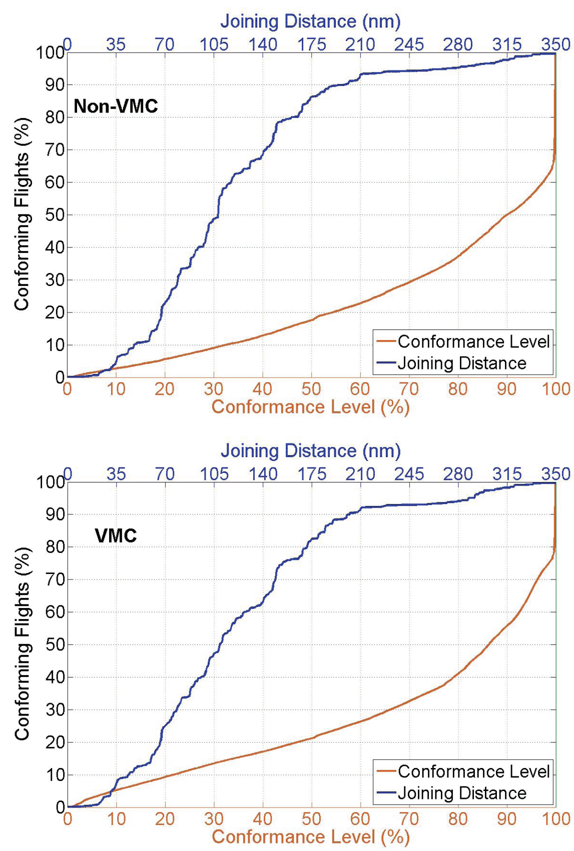

Figure 1-6 – Cumulative Distributions of Procedure Conformance Level and Joining Distance at Airports With FY13 Implementations of RNAV STARs With OPDs

Flights arriving between 6 AM and 11 PM local time exhibit higher conformance to the procedures. Eighty percent of the flights arriving during the typical operating hours conform to more than 50 percent of the cleared procedure, compared to only 45 percent of flights arriving overnight. This is likely a result of

Table 1-4 – Change in Performance Outcomes for All Flights Arriving at Airports With FY13 Implementation of RNAV STARs With OPDs

Airport	Flights in Key Flows	Vertical Profile Performance Outcomes						Other Efficiency Performance Outcome	
		Flights with Step-Descents				Flights with Continuous Descent			
		Number of Level Segments	Time in Level Flight (min)	Distance in Level Flight (nm)	Time Weighted Altitude (feet)	Before	After	Time (min)	Distance (min)
ABQ	85%	1.6 (2%)	4.1 (5%)	22.8 (6%)	18,300 (9%)	32%	31%	43.7 (1%)	263.1 (1%)
ATL	55%	2.7 (1%)	7.8 (5%)	43.8 (3%)	14,800 (-5%)	3%	4%	44.5 (0%)	279.4 (1%)
BNA	89%	2.3 (-20%)	6.8 (-16%)	39.6 (-15%)	19,000 (14%)	3%	12%	44.1 (0%)	264.9 (0%)
CLT	25%	3.4 (2%)	9.2 (2%)	50.9 (2%)	15,400 (-1%)	1%	2%	46.4 (0%)	279.8 (1%)
DEN	88%	2.0 (-10%)	5.5 (1%)	29.9 (2%)	17,700 (5%)	12%	20%	45.2 (1%)	273.1 (1%)
MDW	47%	4.2 (-2%)	11.7 (-5%)	61.7 (-3%)	13,000 (-1%)	1%	1%	46.4 (-1%)	270.3 (0%)
PDX	39%	1.5 (-8%)	3.1 (-17%)	13.9 (-16%)	7,900 (3%)	30%	40%	48.0 (-5%)	287.7 (-4%)
RDU	86%	3.0 (-7%)	9.0 (-6%)	55.1 (-5%)	18,500 (3%)	2%	4%	45.4 (0%)	271.9 (0%)
SEA	44%	1.5 (-3%)	2.9 (-6%)	13.4 (-7%)	9,200 (-4%)	31%	40%	46.0 (-3%)	279.2 (-1%)
STL	90%	2.2 (-8%)	6.0 (1%)	35.7 (3%)	19,200 (8%)	8%	13%	43.9 (0%)	269.4 (0%)
TEB	40%	4.5 (2%)	14.2 (0%)	71.8 (0%)	10,200 (0%)	1%	1%	46.0 (0%)	269.7 (0%)
AVG	**62%**	**2.5 (-8%)**	**6.9 (-6%)**	**38.1 (-6%)**	**15,500 (5%)**	**9%**	**14%**	**45.3 (0%)**	**275.0 (0%)**

Table 1-5 – Change in Performance Outcomes for All Flights Departing From Airports With FY13 Implementations of RNAV STARs with OPDs

Airport	Vertical Profile Performance Outcomes						Other Efficiency Performance Outcome	
	Flights with Step-Descents				Flights with Continuous Ascent			
	Number of Level Segments	Time in Level Flight (min)	Distance in Level Flight (nm)	Time Weighted Altitude (feet)	Before	After	Time (min)	Distance (min)
ABQ	1.2 (1%)	3.5 (-1%)	22.2 (-2%)	27,100 (-1%)	77%	78%	41.7 (1%)	260.4 (0%)
ATL	1.3 (1%)	3.0 (0%)	20.5 (1%)	21,900 (0%)	66%	71%	37.9 (-1%)	263.2 (0%)
BNA	1.3 (1%)	3.0 (1%)	20.0 (0%)	25,200 (-6%)	68%	68%	39.5 (0%)	256.2 (0%)
CLT	1.4 (1%)	3.2 (3%)	21.3 (7%)	23,200 (5%)	61%	65%	40.4 (-1%)	263.4 (0%)
DEN	1.3 (0%)	3.2 (-4%)	22.1 (-5%)	26,600 (-3%)	72%	73%	38.5 (0%)	256.4 (0%)
MDW	1.5 (1%)	2.9 (0%)	17.2 (4%)	17,100 (2%)	51%	49%	38.5 (-1%)	255.7 (0%)
PDX	1.1 (0%)	3.2 (-2%)	20.7 (-5%)	26,200 (-2%)	90%	90%	45.1 (-1%)	303.0 (-1%)
RDU	1.5 (3%)	3.6 (6%)	22.7 (7%)	24,300 (3%)	56%	59%	42.6 (-1%)	263.9 (-1%)
SEA	1.1 (0%)	2.8 (-7%)	18.3 (-8%)	19,200 (-3%)	87%	88%	44.2 (0%)	307.4 (1%)
STL	1.3 (-1%)	3.1 (-1%)	21.5 (-1%)	27,200 (-2%)	68%	71%	38.6 (0%)	258.2 (0%)
TEB	1.6 (0%)	3.8 (-1%)	20.8 (0%)	17,300 (-2%)	32%	37%	44.4 (-1%)	263.6 (1%)
AVG	**1.3 (0%)**	**3.1 (1%)**	**20.9 (2%)**	**23,800 (4%)**	**67%**	**70%**	**40.1 (0%)**	**266.0 (0%)**

flights receiving shortcuts during low traffic levels in the middle of night.

Conformance to RNAV STARs with OPDs varies with procedure design and weather conditions. For instance, at BNA, the STARs are much shorter and 90 percent of flights join the STAR within the last 90 nm of the airport (Fig. 1-7). However, the STARs at DEN are much longer and extend to about 350 nm from the airport. As a result, it is impossible to standardize conformance evaluation across all of the NAS procedures by selecting thresholds for joining distance and conformance level. Instead, procedure conformance analysis needs to take into account a wide range of possible values to provide for understanding the differences in procedure use from one location to another.

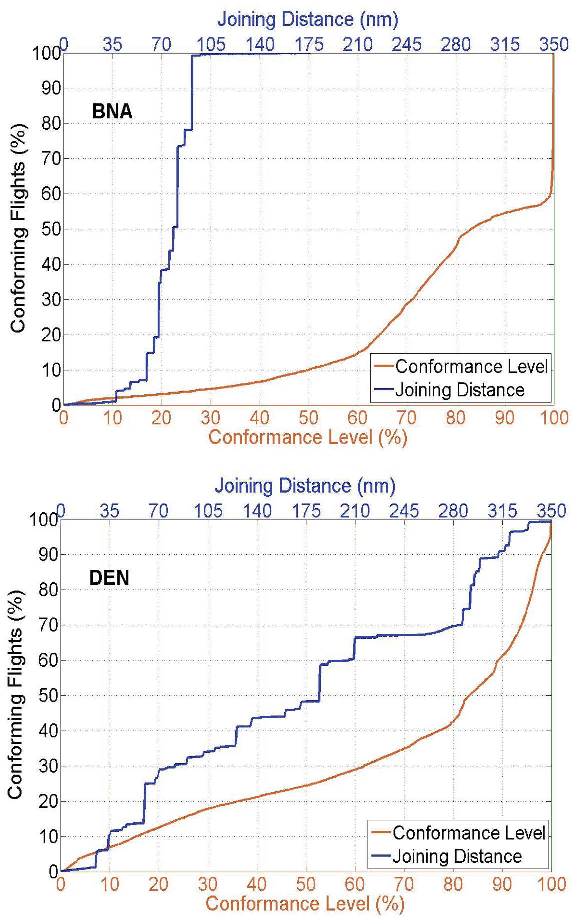

Figure 1-7 – Cumulative Distributions of Procedure Conformance Level and Joining Distance at BNA (left) and DEN (right)

EQUIVALENT LATERAL SPACING OPERATIONS AT ATLANTA HARTSFIELD-JACKSON INTERNATIONAL AIRPORT

Conventional radar separation standards require 3 nm of separation between departures taking off from the same or parallel runways. For aircraft that diverge immediately after departure from parallel runways separated by at least 2500 feet, simultaneous departures are permitted. Conventional separation requires divergence of at least 15 degrees, which achieves

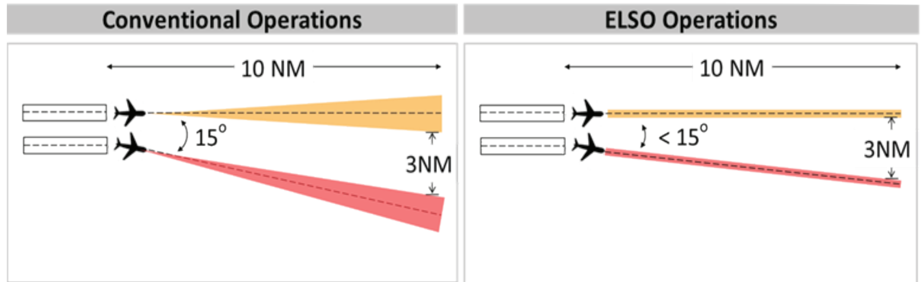

Figure 1-8 – Equivalent Lateral Separation With Less Divergence

3 nm of separation about 10 nm from the points of departure. The Equivalent Lateral Spacing Operations (ELSO) standard is a modification to this divergence requirement that capitalizes on the precision of PBN. ELSO reduces the required angle for departures that use RNAV SIDs by leveraging more precise knowledge about where aircraft will fly. The ELSO standard achieves the same lateral spacing as the conventional standard by accounting for improved navigation performance, runway centerline spacing, and runway stagger (Fig. 1-8). With ELSO, it is possible to redesign airspace to include more diverging SIDs from a set of runways so that more departures capitalize on the reduced divergence separation requirement. The benefits include less time between such departures, greater capacity and less delay.

On October 20, 2011, the FAA published redesigned RNAV SIDs for Atlanta Hartsfield-Jackson International Airport (ATL) to take advantage of ELSO. In east operations, departures primarily use Runways 08R and 09L and sometimes Runway 10. In west operations, they primarily use Runways 26L and 27R and sometimes Runway 28. Before ELSO, three departure routes were available in dual and triple runway configurations for both east and west operations (Fig. 1-9). Some of these configurations required controllers to issue radar vectors rather than to clear flights to fly SIDs, increasing workload and introducing inconsistent operational practices day to day. With ELSO, four departure routes, all RNAV SIDs, are available in all configurations. The new design includes a second route off Runway 08R and another off Runway 27R, allowing reduced divergence separation between successive departures if using different SIDs.

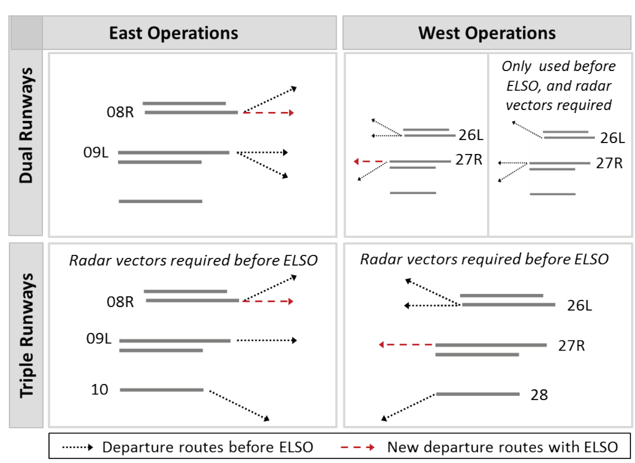

Figure 1-9 – Departure Routes Before and With ELSO

We anticipated a number of operational benefits. The immediate effect of reduced divergence separation between successive departures is that less time is required between them. The greater capacities of Runways 08R and 27R should be reflected in greater overall airport capacity, more efficient surface operations, smaller departure delays and shorter queues.

We used the following data sources to analyze the actual benefits:

- ASPM – ASPM was the source for throughput, airport departure rates, runway configurations, and meteorological conditions.
- Airport Surface Detection Equipment Model X (ASDE-X) – ASDE-X and the MITRE Corporation's Ground Tracker tool[8] were the source for queue lengths and times in queue.
- The MITRE Corporation's Threaded Track data – Threaded Track is a fusion of data from the National Offload Program, ASDE-X, and the Traffic Flow Management System message set. Threaded Track was the primary source of departure event information including time, runway, equipment type, and SID.

This assessment considered 168 sample days from October 2010 to September 2011, ending just before the new ELSO-enabled SIDs were published, and October 2012 to September 2013, starting a year afterward. During the interim year, a new international terminal opened, Runway 09L/27R was extended to the east, and a new taxiway was commissioned to its north. We selected the sample days to represent a mix of east and west operations, visual and instrument meteorological conditions (VMC and IMC), and weekdays and weekends.

This assessment found differences in performance to be consistent with the above expectations. These results are also consistent with those of a prior study conducted by the MITRE Corporation as requested by the FAA in 2012 [6].

The direct effect of the additional SIDs off Runways 08R and 27R is shorter inter-departure times for many successive departures (Fig. 1-10)[9]. With ELSO, smaller inter-departure times are evident for both runways when wake separation is not a concern. For Runway 08R, the mode of inter-departure times

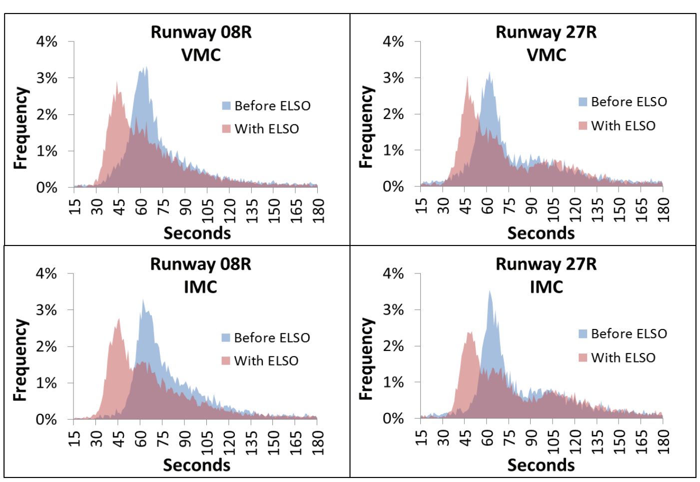

Figure 1-10 – Times Between Successive Departures From Runways 08R and 27R

decreases from 62 to 44 seconds in VMC and from 62 to 46 seconds in IMC. For Runway 27R, the mode decreases from 62 to 47 seconds in VMC and from 62 to 50 seconds in IMC. These decreases are consistent with the relaxed separation requirement for diverging departures. Some other features of inter-departure times warrant explanation:

- For both runways, some inter-departure times remain the same with ELSO because some successive departures do not diverge.
- In addition, in IMC, some inter-departure times remain the same with ELSO because the trailing departure must be separated from arrivals to Runways 08L and 27L.
- The large number of inter-departure times for Runway 27R between 100 and 120 seconds represent successive departures interrupted by Runway 27L arrivals crossing Runway 27R.

The improved capacities of Runways 08R and 27R are apparent in the Airport Departure Rates (ADR), which increased by 5 to 10 percent for dual runway configurations and somewhat less for triple runway configurations (Table 1-6). The only decrease in ADRs was for the triple runway configuration in VMC east operations, but the airport used the configuration in only 0.7 percent of VMC hours with ELSO.

Table 1-6 – Airport Departure Rates and Frequency of Departure Configurations

Configuration	Visual Conditions Average ADR and Share of Operating Time		Instrument Conditions Average ADR and Share of Operating Time	
	Before ELSO	With ELSO	Before ELSO	With ELSO
East Operations 2 Departure Runways	105.4 24.2%	110.5 34.3%	93.6 51.3%	102.8 55.3%
West Operations 2 Departure Runways	98.7 68.4%	104.2 63.6%	93.5 42.8%	99.4 43.1%
East Operations 3 Departure Runways	119.8 1.4%	113.1 0.7%	111.0 2.8%	113.0 0.2%
West Operations 3 Departure Runways	116.6 5.9%	118.0 1.4%	111.5 3.2%	114.6 1.3%
All Operations	101.7 7,247 hours	106.6 6,265 hours	94.6 1,457 hours	101.5 2,458 hours

Greater frequency of east operations with ELSO is due to prevalence of winds rather than a change in operational strategy (Table 1-6). However, the shift from triple to dual departure runway configurations is pronounced. The same data underlying Table 1-6 show that the use of three departure runways decreased from 5.4 to 1.4 percent of the time in east operations and from 7.8 to 2.3 percent of the time in west operations. Use of Runway

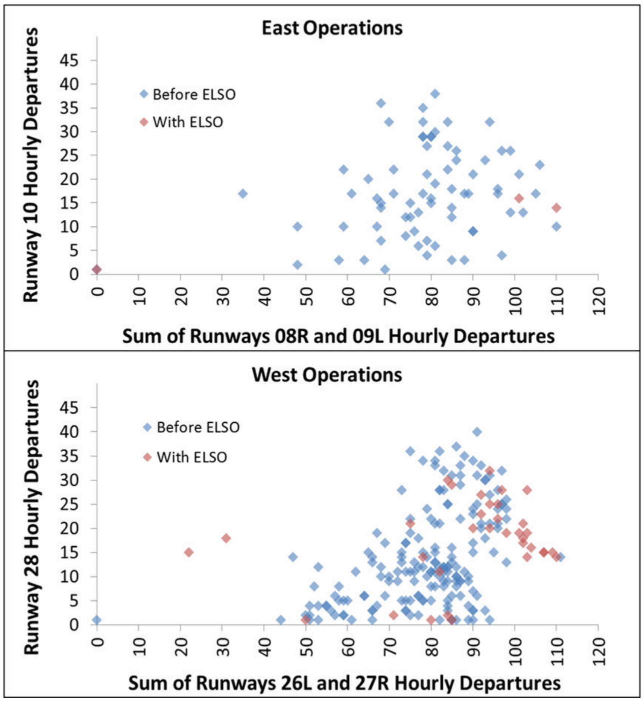

Figure 1-11 – Use of Runway 10/28 to Offload Departures

10/28 as an offload runway with ELSO occurs mainly when throughput on the primary runways is very high (Fig. 1-11). Each departure able to use the inner runways instead of Runway 10/28 has reduced taxi time, avoids crossing Runway 09R/27L, and avoids interfering with arrivals to Runway 10/28.

The distributions of departure traffic among runways are very similar in VMC and IMC (Table 1-7). With ELSO, departures use Runway 10/28 less frequently. In east operations before ELSO, 2.4 percent of departures used Runway 10, decreasing to 0.2 percent of departures with ELSO. In west operations before ELSO, 3.9 percent of departures used Runway 28, decreasing to

Table 1-7 – Distribution of Departures Among Runways

Runway		Before ELSO	With ELSO
East Operations	08R	48.9%	54.3%
	09L	48.6%	43.7%
	10	2.4%	0.2%
	08L	0.0%	0.2%
	09R	0.1%	1.5%
West Operations	26L	54.2%	54.6%
	27R	41.7%	42.8%
	28	3.9%	2.1%
	26R	0.2%	0.1%
	27L	0.1%	0.4%

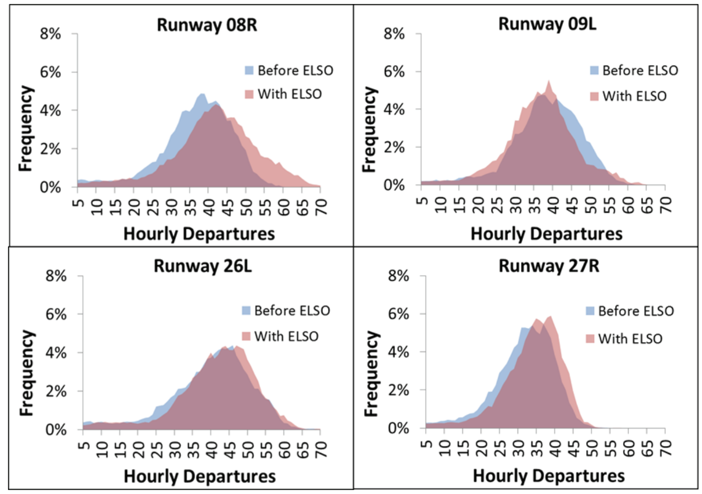

Figure 1-12 – Throughput on Primary Departure Runways

2.1 percent of departures with ELSO.

Note that the distribution of traffic between Runways 26L and 27R was about the same before and with ELSO. After ELSO was implemented, the distribution of traffic between Runways 08R and 09L changed and now matches the distribution between Runways 26L and 27R. It is more efficient to have flights flying westbound SIDs depart from the north side of the airport, and now Runway 08R can accommodate more of these. In fact, 9.0 percent of the departures off Runway 09L before ELSO used westbound SIDs, but this decreased to 3.2 percent of departures with ELSO. The share of Runway 08R departures that were westbound grew from 42.3 to 45.2 percent. This is one reason for the greater throughput of Runway 08R (Fig.1-12). Note that these increases in throughput on Runways 08R, 26L, and 27R all occur despite a decrease of about 2 percent in overall demand at ATL.

We find that times in queue are less with ELSO despite the less frequent use of the higher capacity triple departure runway configurations. This is partly due to lower demand, but also to the higher capacities of Runways 08R and 27R. Moreover, the greatest decrease of average time in queue is for departures off Runway 08R, which saw the greatest increase in traffic. The average times in queue for Runways 09L and 26L change only slightly by 18 and 15 seconds, respectively (Fig. 1-13). However,

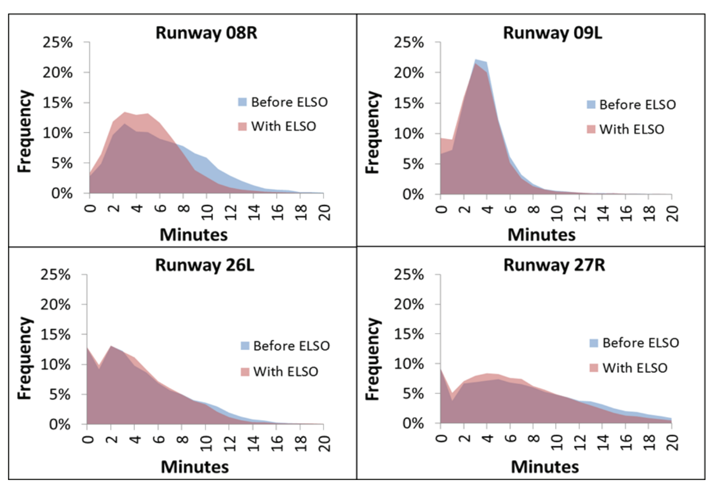

Figure 1-13 – Distribution of Time in Departure Queue

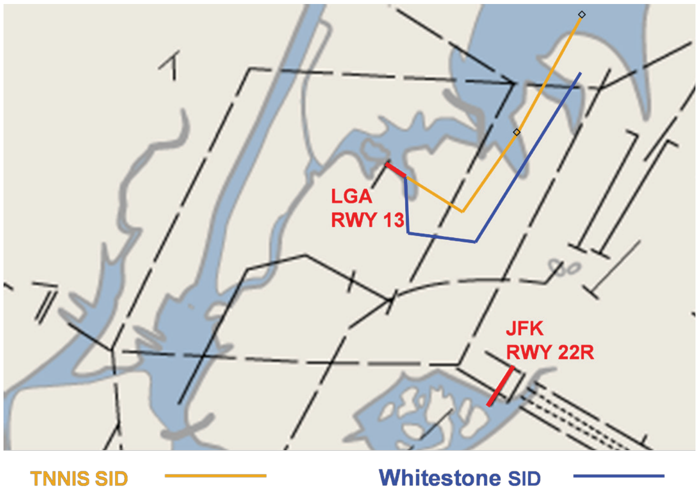

Figure 1-14 – Physical Layouts of the TNNIS and Whitestone SIDs

the average times in queue for Runways 08R and 27R change more dramatically by 70 and 64 seconds, respectively.

Not only do flights spend less time in the queues for Runways 08R, 09L, 26L, and 27R, but also many of these flights avoid taxiing to Runway 10/28. Average taxi-out times to the south runway are different for east and west operations before and with ELSO. They range between 16 and 20 minutes, including averages of three to five minutes of time in queue. In contrast, the average taxi-out times to the primary departure runways range between 10 and 14 minutes, including averages of four to nine minutes of time in queue. The taxi-out times to the various runway ends differ before and with ELSO for many reasons, but the ability to accommodate more traffic on the primary runways saves many flights from the long taxi to the south runway.

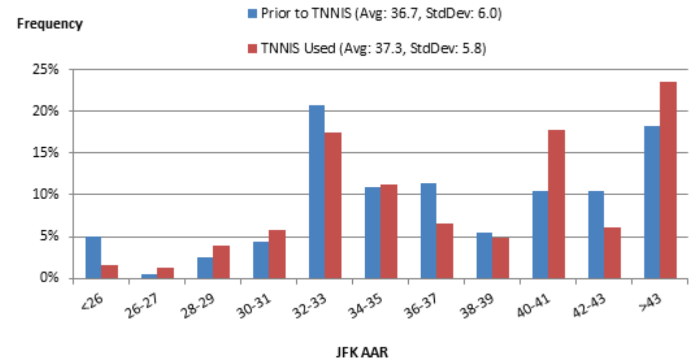

Figure 1-16 – Distribution of JFK Airport Arrival Rates in Non-VMC Peak Hours

OPERATIONAL PERFORMANCE IMPACTS OF TNNIS RNAV SID AT LAGUARDIA AIRPORT

The TNNIS RNAV SID enables more accurate navigation for La Guardia Airport (LGA) departures. Prior to TNNIS publication, simultaneous departures from LGA Runway 13 and arrivals to John F. Kennedy International Airport (JFK) Runway 22R were not possible due to insufficient spacing between those flows. The TNNIS SID enables a tighter flow of departures from LGA that is also further away from JFK airspace, allowing JFK arrivals to land to Runway 22R (Fig. 1-14). The increased spacing between the flows also enables JFK arrivals to use the ILS approach to Runway 22L/R when LGA is using Runway 13 for departures. The TNNIS SID is an example of PBN alleviating interaction between adjacent airport flows, improving system-wide performance.

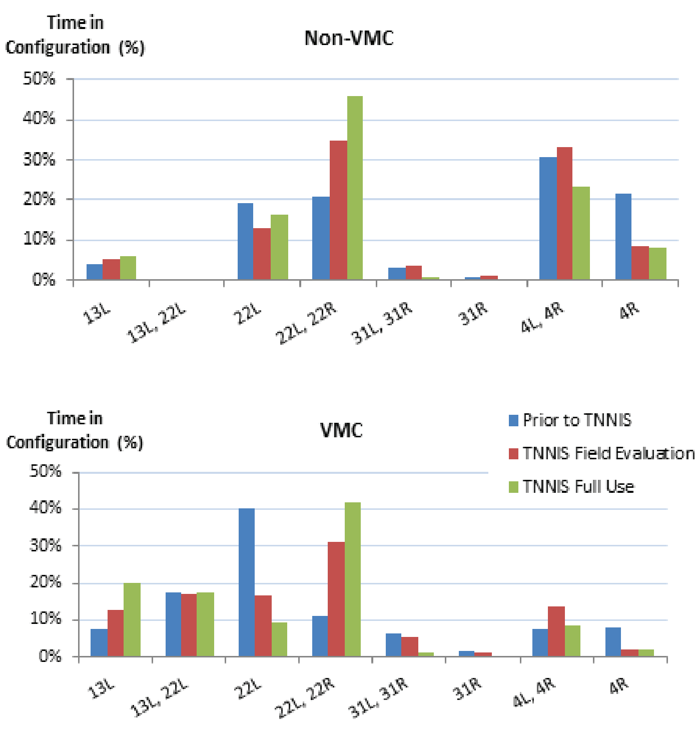

Figure 1-15 – JFK Arrival Runway Configurations When LGA Departures Use RWY 13

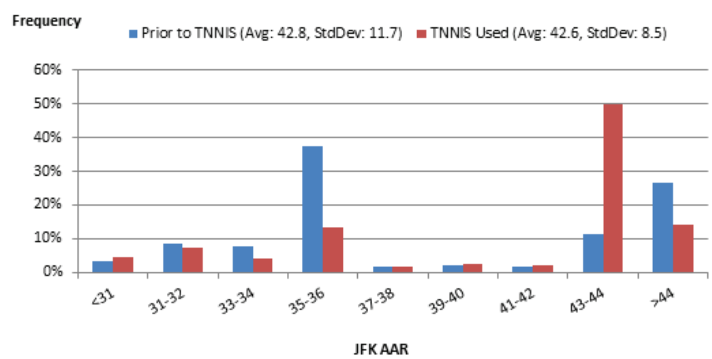

Figure 1-17 – Distribution of JFK Airport Arrival Rates in VMC Peak Hours

Our analysis focuses on changes in JFK arrival capacity and throughput because of the TNNIS SID. Based on the reasons mentioned above, we expect to observe increases in JFK arrival capacity and throughput. We use data from the ASPM between January 2011 and September 2013, and compare JFK arrival capacity and throughput during periods when TNNIS was unavailable to those when TNNIS was in use. The comparisons are limited to peak hours, identified as the hours when arrival demand is at least 70 percent of Airport Arrival Rates (AAR).

We observe that, since the implementation of the TNNIS RNAV SID, JFK is able to conduct arrivals on Runways 22L and 22R in peak hours more often than before (Fig. 1-15). This finding is apparent for both the TNNIS field evaluation phase (February

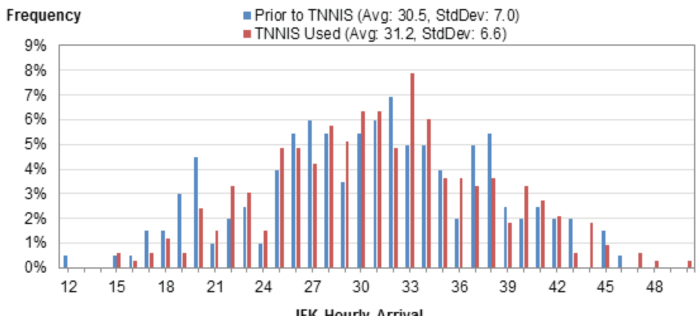

Figure 1-18 – Distribution of JFK Arrival Throughput in Non-VMC Peak Hours

2012 to March 2013) and the period following the procedure's final approval (March to September 2013).

TNNIS implementation corresponds with improvements in JFK arrival capacity during peak hours. In non-VMC, when departures from LGA Runway 13 use the TNNIS SID, JFK uses high-end AARs more frequently, and reduces the instances of low AAR use (Fig. 1-16). In VMC, although AARs at JFK did not significantly change on average, their standard deviation is now noticeably lower, implying more predictable arrival capacity (Fig. 1-17).

Similarly, JFK arrival throughput during peak hours also improved because of the TNNIS SID. In non-VMC, the arrival throughput is over 2 percent higher on average when TNNIS is used (Fig. 1-18). In VMC, there is less variation in arrival throughput when TNNIS is in use, even though the average throughput did not change considerably (Fig. 1-19). These findings are consistent with the observed impacts of TNNIS use on JFK arrival capacity.

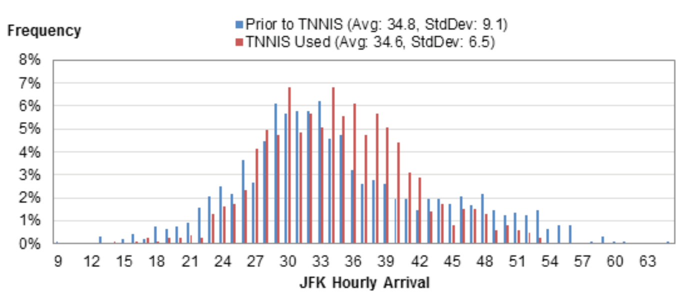

Figure 1-19 – Distribution of JFK Arrival Throughput in VMC Peak Hours

ANALYSIS OF Q-ROUTE INVENTORY AND EQUIPAGE

This section of our assessment focuses on flight efficiency impacts of Q-routes available NAS-wide in FY 2013.
By the end of FY2013, the FAA had implemented 80 T-routes and 94 Q-routes, representing about 11 percent and 24 percent of all en route airways in low- and high-altitude airspace, respectively (Fig. 1-20). The FAA published these PBN routes only where deemed beneficial or required to support operational needs.

Low-altitude T-routes, designed to facilitate traffic flows by providing safe and efficient navigation around SUA, improve access to Class B/C airspace that had typically been

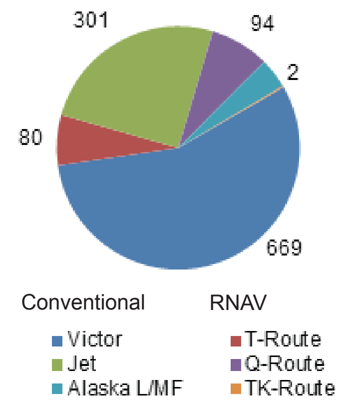

Figure 1-20 – En Route Airways in the NAS

circumnavigated in the past. In areas of high terrain, they are designed to enable lower minimum altitudes, resulting in not only improved airspace use and operator efficiency, but also improved safety because of reduced icing risk.

High-altitude Q-routes are designed to alleviate flow interaction and airspace complexity in corridors with high traffic volume, resulting in reduced controller workload and sometimes increased airspace capacity. In less congested airspace, they are designed to aid controllers by maintaining predictability of traffic flows and interactions while also supporting more flexible point-to-point navigation.

The FAA continues to review and revise the route structure, implementing PBN routes where they can mitigate operational restrictions and address user needs (Fig. 1-21).

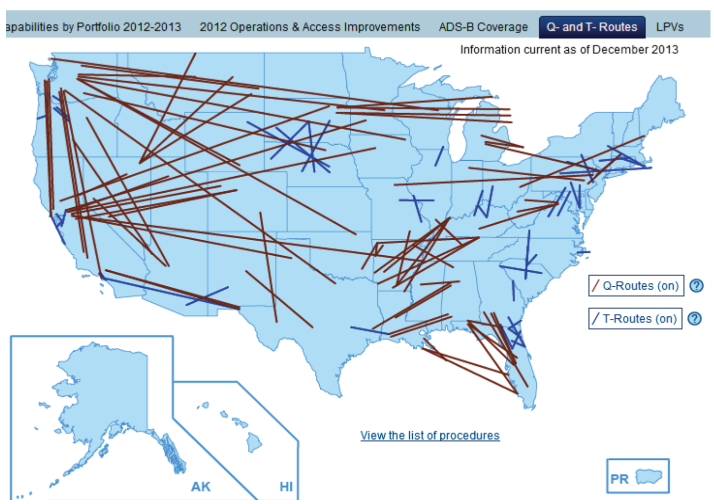

Figure 1-21 – PBN Airway Inventory as of December 2013

Analysis of Operational Impacts: Q-Routes

Our analysis focuses on domestic flights in FY 2013. Since actual utilization of Q-routes is not available, we consider routing requests recorded in the last filed flight plan before departure, and compare performance outcomes of flights that requested to fly Q-routes to the outcomes of flights that did not.

By the end of FY 2013, the FAA had implemented 94 Q-routes across the NAS. Requests for these routes were not uniformly spread across the inventory. Although 90 percent of these routes were requested at least once, most of the routes were requested quite rarely while the top third accounted for almost 95 percent of all requests (Fig. 1-22).

Q-routes were also not uniformly requested across the flights or airport pairs. Only 3 percent of domestic flights in FY 2013 filed for a Q-route, serving about 2 percent of the domestic airport pairs with filed flight plans (Fig. 1-23).

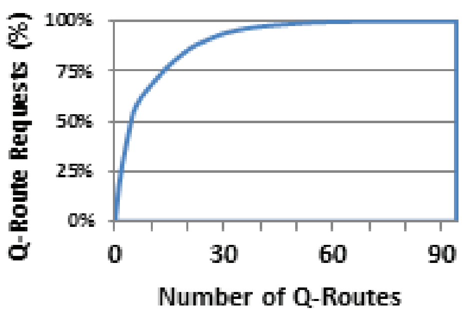

Figure 1-22 – Distribution of Q-Route Requests by Inventory

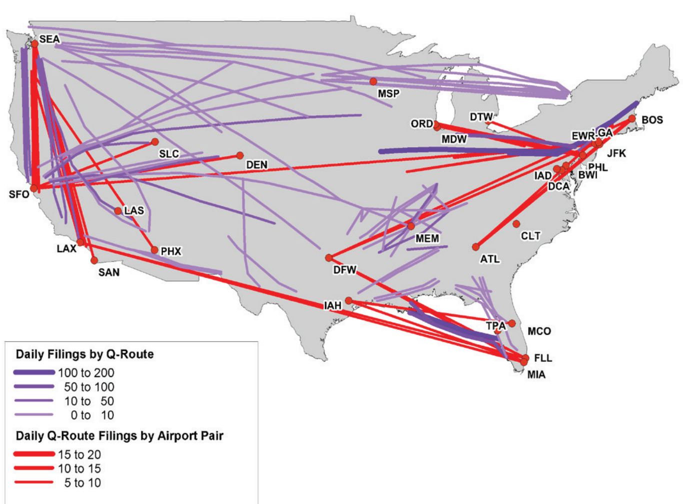

Figure 1-23 – Average Daily Q-Route Requests in FY 2013

However, most of the flights in the NAS do not repeat on a daily basis, and the vast majority of airport pairs are rarely flown. In fact, in FY 2013, 90 percent of all flight plans were filed between only 7 percent of the airport pairs. It would be impossible to build a national routing structure to support such a wide range of operational needs. Therefore, our airway design focuses on operational needs of frequently flown routes, as does the following analysis.

To compare differences in performance outcomes of flights requesting Q-routes with those of flights requesting other routing options between the same origin and destination, we identified airport pairs served by Airline Service Quality Performance reporting flights with daily service and mixed routing requests. We found 249 airport pairs in FY 2103 that met the criteria. For each of the flights serving these airport pairs, we evaluated arrival delay, as well as the excess of actual distance flown over great circle distance (GCD). Since GCD is the shortest distance a flight can fly, the difference between actual flown distance and GCD is an indicator of flight efficiency in the absence of winds.

Compared to other aircraft on the same markets, aircraft requesting Q-routes achieved two minutes less arrival delays and 14 nm less excess distance on average (Table 1-8). A more detailed analysis indicates that between 9 and 86 percent of flights serving these airport pairs request Q routes (Fig. 1-24). Average excess distance between airports with higher proportion of flights requesting Q-routes is typically lower. In addition, on the high-end, it reaches 52 nm for the aircraft requesting Q-routes, and 82 nm for those requesting other routing options[11]. To understand whether requests to fly Q-routes vary based on the distance between origin and destination airports, we compared performance outcomes by grouping flights into five categories of GCD between their origin and destination in increments of 500 nm (Fig. 1-25). We observed shorter excess distance and arrival delay for aircraft requesting Q-routes irrespective of their GCD category, with the highest difference of 22 nm in average excess distance and five minutes in average arrival delay between airports with GCD of up to 1,000 nm. Not surprisingly, 68 percent of all the Q-route requests were observed between

Table 1-8 – Arrival Delay and Excess Distance for Top 249 Airport Pairs

	Flights Requesting Q-routes		Flights Requesting other Routing Options		Difference
	Avg.	S.D.	Avg.	S.D.	
Excess Distance (nm)	49.85	31.05	63.73	44.68	22%
Arrival Delay (min)	8.22	22.50	10.31	25.18	20%

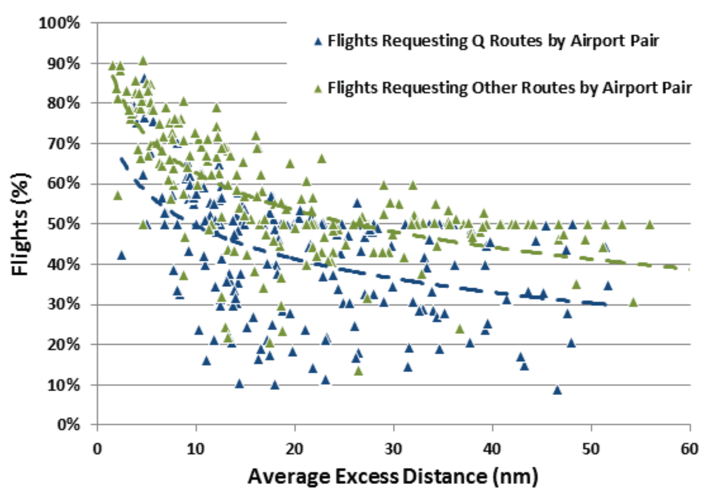

Figure 1-24 – Correlation Between Excess Distance and Proportion of Flights Requesting Different Routing Options for Top 249 Airport Pairs

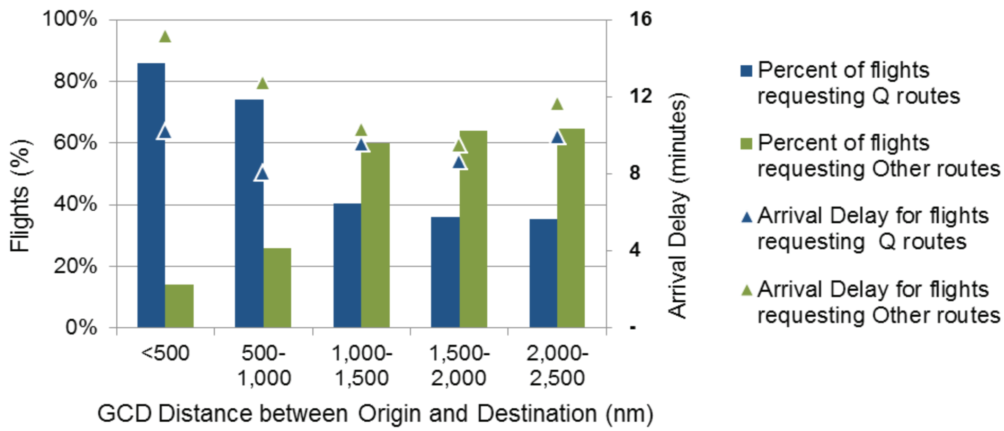

Figure 1-25 – Average Arrival Delay by GCD Between Airports

airports with GCD of up to 1,000 nm.

In addition, flights requesting Q-routes also experience less variance in excess distance and arrival delay (Fig. 1-26).

Compared to the aircraft requesting other routing options, the standard deviation of excess distances is 32 percent smaller for the aircraft requesting Q-routes, and that of observed arrival delays 11 percent smaller.

Finally, we conducted a regression analysis to examine not only the impact of choosing a Q-route but also other causal factors such as distance and weather (using the Weather Impacted Traffic Index, or WITI[11]).

The outcome of the regression analysis indicates that aircraft requesting Q-routes fly 1 percent lower excess distance per mile of GCD. For example, this means that aircraft requesting Q-routes fly on average 4 nm of excess distance for every 100 nm of GCD, whereas aircraft requesting other routing options fly on average 5 nm of excess distance for every 100 nm of GCD. Weather, on the other hand, has no significant impact on excess distance.

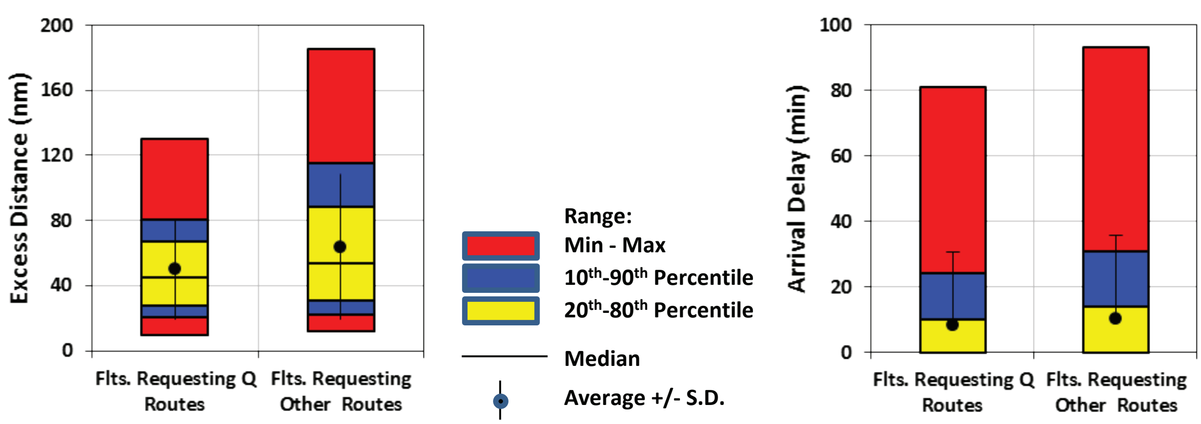

Figure 1-26 – Excess Distance and Arrival Delay: Range of Observed Outcomes

CONCLUSIONS

In order to make air traffic more predictable and easier to manage, the FAA maintains a national network of routes and arrival/departure procedures. Conventional routes and procedures rely on ground-based navigational aids, while PBN routes and procedures leverage emerging technologies such as GNSS. PBN not only provides for modernization of the existing navigation infrastructure and services, but also for significant benefits to both the FAA and its users. For the FAA, the MON will provide significant cost savings by reducing required flight checks and NAVAID maintenance, and PBN for more flexible, and in some cases more efficient, airspace design. For controllers and pilots, PBN provides workload reduction and safety benefits resulting from more precise navigation. In addition, for operators who have the required PBN capability, PBN provides access to the most flexible routing options during nominal operations and, in some cases, improvements in flight efficiency and increased access to airports. This assessment focused on impacts of RNAV STARs with OPDs implemented in FY 2013, RNAV SIDs at Atlanta and LaGuardia airports, and Q-routes available NAS-wide.

Starting in the terminal areas across the NAS, we investigated the typical use of the new RNAV STARs with OPDs by evaluating lateral conformance and utilization levels. Across the 11 airports with recent OPD implementations, conformance in non-VMC is higher due to fewer shortcuts, and about half of arrivals conform to at least 90 percent of the procedure distance after their joining waypoint. However, conformance and utilization levels vary by location, weather conditions, and time of day, making it difficult to develop standard definitions for their evaluation. Quite often, flights do not follow the published procedures from beginning to end, and such partial use may in fact lead to enhanced benefits because flights take advantage of shortcuts and "Direct-To" clearances when possible. As a result, although related to benefits, utilization is not a good indicator of benefits.

As expected, the most significant benefit from the FY 2013 implementation of RNAV STARs with OPDs was more efficient vertical profiles. Flights arriving via traffic flows in position to use the new procedures now start their descent about 7 nm or 4 percent closer to their destination. The proportion of flights with continuous descents increased from 9 to 16 percent, while those that level off now experience 12 percent fewer level segments, and 8 percent less time and distance in level flight. Furthermore, the remaining level segments occurred at higher altitudes. Although not directly estimated, these results also indicate fuel savings resulting from longer cruise portions of the flight and more efficient descents.

RNAV STARs with OPDs yielded system-level benefits as well. On average, all arrivals to airports with newly implemented OPDs experienced more efficient descents. Not only did the proportion of flights with continuous descents increase from 9 to 14 percent across all arrivals, but the arrivals with step-descents flew 6 percent shorter time and 6 percent shorter distance in level flight as well. Airports where the new procedures cover all corner posts typically experienced more significant improvement in descent efficiency. Although not as significant, departure efficiency improved as well, further demonstrating benefits at the system level.

The ELSO concept took advantage of advanced navigation capabilities to create more departure routes in the same airspace while maintaining the same spacing as conventional separation standards. In October 2011, the FAA published redesigned RNAV SIDs at ATL, incorporating ELSO and providing a fourth departure route in most configurations. Controllers can now sequence departures off Runways 08R and 27R so that they follow divergent headings and require less separation than if they remained in-trail.

Here, benefits include reduced times between successive departures off Runways 08R and 27R, which have decreased between 8 and 18 seconds depending on weather and direction of operations. The improved capacity of these runways has enabled 1.2 percent more traffic to use the primary runways in east operations and 0.8 percent more in west operations. By avoiding the long taxi path to Runway 10/28, these departures avoid taxi-out routes that are about six minutes longer. In east operations, more traffic is using Runway 08R, which allows better segregation of departures headed in different directions between the north and south sides of the airport. Despite greater reliance on the primary runways, average times in departure queues have decreased by over a minute for Runways 08R and 27R, or 15 percent and 11 percent of their average times in queue, respectively.

The TNNIS RNAV SID enables a tighter flow of departures from LGA and is further away from JFK airspace. As a result, the new procedure enables simultaneous departures from LGA Runway 13 and arrivals to JFK Runway 22R, which was not possible in the past.

The TNNIS SID is an example of PBN alleviating an interaction between adjacent airport flows, resulting in system-wide benefits. It leverages improved navigational accuracy for LGA departures, allowing more predictable and efficient arrival operations at JFK. Not only is JFK now able to use its preferred arrival runway configuration more often, it is also able to use high-end AARs more often. As a result, when LGA uses Runway 13 for departures, the arrival throughput at JFK is over 2 percent higher on average in non-VMC, and exhibits significantly less variance in VMC. Both of these outcomes contribute to smoother and more efficient arrival flows at JFK. Finally, looking at the en route airspace, by the end of FY 2013 94 Q-routes were available across the NAS. Operators requested each of the routes to some extent. However, about a third of the routes accounted for 95 percent of all requests, clearly demonstrating that operators use existing structure only when beneficial. Although only about 3 percent of flights request to fly Q-routes on a daily basis, the actual use is a lot higher between airport pairs where the routes are both close to the direct path between the origin and destination, and efficiently connected with corresponding SIDs and STARs. Compared to other flights between the same airport pairs, those that request Q-routes experience 14 nm and two minutes shorter excess distance and arrival delay on average.

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ENDNOTES

[1] Current NAVAID decommissioning is a part of regular maintenance and update schedule prior to the VOR MON. The Final Investment Decision for the VOR MON Program is currently scheduled for Spring of 2015.
[2] Nominal operations in this instance are characterized as routine air traffic operations affected by only typical disruptions. Off-nominal operations are those affected by equipment outages, security threats, major weather events, etc.
[3] Low altitude en route airspace includes altitudes up to FL180, while high-altitude airspace is above FL180. TK routes are available for en route IFR helicopter operations.
[4] Time-weighted altitude (TWA) is an indicator of efficiency of vertical profiles below top of descent. It focuses on level segments below top of descent, and represents an average of all altitudes where an aircraft leveled off weighted by the percent of overall time in level flight spent on each of the altitudes. For instance, if two flights level off at exactly the same altitudes, the one that spends longer time in level flight at the higher altitude will have higher TWA. Also, if two flights spend exactly the same amount of time in level flight at different altitudes, the one that leveled off at higher altitudes will have higher TWA.
[5] This analysis adopts the PBN Dashboard methodology for determining level segments; level segments must occur below TOD and have a change in altitude of less than 200 feet for at least 50 seconds.
[6] Although Time within 250 nm has decreased at MDW as well, the finding is not significant due to the short period over which performance was evaluated after the implementation of the new procedures.
[7] We used the same methodology implemented in the PBN Dashboard to determine procedure conformance.
[8] The Ground Tracker tool infers aircraft surface movement status and queue position by superimposing ASDE-X data onto a digitized airport surface map.
[9] We do not address triple runway configurations here for two reasons. In east operations with ELSO, use of the triple runway configuration is rare, which is discussed further below. In the triple runway configuration for west operations with ELSO, only one departure route off Runway 27R is used.
[10] The high-end excess distances for flights requesting Q routes and flights requesting other routes were observed for different airport pairs.
[11] WITI is an indicator of weather and traffic demand impact on the NAS. It measures the location and severity of weather and its impact on traffic, incorporating both en route convective weather and terminal surface weather. AvMet Applications provided WITI data used for this analysis.


N5897S

TIME BASED FLOW MANAGEMENT

To regulate air traffic flows throughout the National Airspace System (NAS), FAA traffic managers employ a number of techniques called Traffic Management Initiatives (TMI). Since the early days of air traffic management, TMIs have been used to lower the rate of air traffic through NAS resources during periods when demand is expected to exceed capacity. For instance, ground stops and Ground Delay Programs (GDP) keep flights on the ground at their origin airports, while Mile-In-Trail (MIT) restrictions space flights at key points in the airspace.

Time based metering is another technique traffic managers and controllers use to govern arrival flows. When metering arrivals to an airport, an automation system maintains a near-term schedule of runway assignments and landing times. It monitors the progress of these arrivals and periodically computes the delay each must absorb to realize the planned schedule. The system allocates an arrival's delay to various segments of the flight to balance the traffic loads on different components of the system along the flight's path. Delays to be absorbed in the air are shared with en route controllers at their workstations, who then use speed controls, vectoring, and holding to realize these delays. Delays to be taken on the ground are shared with traffic management units in Air Route Traffic Control Centers (ARTCC) who, in turn, approve Air Traffic Control Tower (ATCT) requests to issue departure clearances.

The current automation system that supports arrival metering started as Traffic Management Advisor (TMA). Developed in the 1990s, TMA was originally deployed at Fort Worth ARTCC and by 2007 expanded to all 20 ARTCCS. In the evolution toward NextGen, TMA underwent a technology refresh in the summer of 2013 and became Time Based Flow Management (TBFM).

Additional enhancements to the TBFM software are expected to be deployed over the next several years that will provide extended metering, automated speed advisories, and integrated departure and arrival capability. TBFM automation, deployed at 20 ARTCCs, 25 Terminal Radar Approach Control (TRACON) facilities and 33 ATCTs, is currently used to manage arrival flows to 24 of the Core 30 airports. Some facilities have yet to incorporate TBFM into their flow management strategies or have scaled back use of TBFM in recent years in conjunction with declining traffic.

TBFM metering is initiated and administered by traffic managers in the ARTCC or TRACON of the arrival airport. As a decision support system, controllers are not compelled to enforce its advisories. TBFM consists of the following key functions:

- Arrival Management/Situational Awareness – TBFM allows traffic managers to monitor the progress of arrivals to an airport and shares projections of demand for its runways and key airspace elements (e.g., arrival fixes). With this enhanced situational awareness, traffic managers can coordinate adjustments in spacing and airspace fix assignment to more efficiently manage air traffic flows. Traffic managers also use the information to decide whether and when various TMIs are needed.
- Airborne Metering – TBFM assigns runways, schedules landing times, computes and allocates airborne delays, and shares its schedule and delay information with en route controllers at their workstations.
- Departure Scheduling – TBFM allows traffic managers to more efficiently manage arrival times

at destination airports by adjusting departure times at their origins. The system calculates appropriate departure times, used by traffic managers when ATCT controllers call the ARTCC traffic management unit (TMU) for approval to release a departure[1].

- En Route Departure Capability (EDC) – TBFM adjusts departure times to achieve more efficient integration of flights into the overhead en route stream.

A major advance in the history of TMA was the introduction in 2003 of the ability to manage arrivals across ARTCC boundaries. To date, this ability has been implemented for 18 of the Core 30 airports. With Single Center Metering (SCM), airborne flights are metered to the boundary of the airport's TRACON as implemented by en route controllers in the airport's ARTCC. Adjacent Center Metering (ACM) provides the ability to meter airborne flights to the boundary of the airport's ARTCC or TRACON as well, but is implemented by controllers in adjacent ARTCCs. Similarly, SCM allows departures from airports within the airport's ARTCC to be managed with Departure Scheduling, while ACM also manages departures from airports in adjacent ARTCCs.

Departure Scheduling is widely used alone as well as with Airborne Metering. For some airports, TBFM is used daily while at others, traffic managers decide to use TBFM on a case-by-case basis. TBFM can reduce or eliminate the need for MIT restrictions, but both approaches are still used for many airports. Ground stops and GDPs, which can be broader in scope and have longer planning horizons than TBFM, are often employed concurrently with TBFM or MIT restrictions.

Relative to other TMIs, TBFM enables more tactical management of arrivals because it considers the fluid, near-term traffic situation in detail and can influence flights at various points prior to their arrival. As such, TBFM aims to improve several aspects of performance. In particular, improved delivery of arrivals to the airport facilitates more efficient use of available capacity, and thereby reduces delays. In addition, allocation of computed delays reduces holding and vectoring and facilitates absorption of delay where fuel burn rates are lower, either on the ground or at higher altitudes.

To assess the impact of TBFM relative to other traffic management strategies, it is necessary to identify and characterize situations in which TBFM functions may result in different traffic flow characteristics and performance. Of interest for these situations are the operating conditions, the traffic management response, and the resulting system performance in terms of delays, airborne times, holding and vectoring. This assessment used a variety of data sources:

- Aviation System Performance Metrics (ASPM) provided airport arrival capacities and demand, and flight delays[2],
- MITRE's TBFM Data Acquisition System, which uses internal TBFM messages, provided Departure Scheduling and Airborne Metering delays sent to controllers,
- National Traffic Management Logs provided MIT restrictions, and
- Traffic Flow Management System provided surveillance data used to reconstruct flight trajectories and identify instances of holding and vectoring.

Taken together, these data sources present a history of arrival flow management for airports where TBFM was used between July 2011 and December 2013. From that history, this assessment identifies and characterizes several themes and trends in TBFM use and examines its operational and performance impacts.

OPERATIONAL PERFORMANCE ASSESSMENT

TBFM has been deployed at all of the Core 30 airports except TPA and HNL. This assessment focused on the usage and performance effects of Departure Scheduling and Airborne Metering for arrival flows to those Core 30 airports where these functions have been used. While the Departure Scheduling and Airborne Metering functions are routinely used at only a handful of the Core airports, the use of these functions varies across facilities (Table 2-1).

Table 2-1 – Use of TBFM Functions (July-December 2013)

		Airborne Metering		
		Routine	Occasional	Rare or Never
Departure Scheduling	Routine	ATL, CLT, EWR, PHX, LAX	DEN, IAH, MSP[1], SEA, SFO	DTW, IAD, LAS, LGA, PHL
Departure Scheduling	Occasional	SLC, SAN	BOS, FLL[2], MEM	BWI, DCA, JFK, ORD
Departure Scheduling	Rare or Never			DFW, MCO, MIA

[1]At ZMP, TBFM automation generates meter fix times even when the Center is not metering to MSP, so data interpretation is difficult.

[2]Use of TBFM for FLL traffic is seasonal, mainly in the winter.

TBFM is usually administered by the arrival airport's Center, but TRACONs N90 and PHL do so for the New York and Philadelphia airports, respectively. Some facilities use only Departure Scheduling, while others prefer Airborne Metering with Departure Scheduling. Some facilities use TBFM daily, while others use it only when traffic managers decide its use would be beneficial. A few interesting facts regarding TBFM use between July 2011 and December 2013 are worth noting:

- BWI and DCA started to use Departure Scheduling in 2012.
- Airborne Metering started at SAN in 2011, but its use has since declined.

- Use of TBFM for JFK arrivals was suspended in early 2012.
- Use of Departure Scheduling has declined at MEM and SLC, and increased at SAN and SFO.
- Use of Airborne Metering has declined at DEN, MEM, DTW, IAD, LAS, PHL, SAN, and SLC.

This assessment considered two common uses of TBFM: Departure Scheduling alone and Airborne Metering (with or without Departure Scheduling). Flights generally have lower arrival and airborne delays when these TBFM functions are used than when they are not. In part, this reflects use of TBFM during more manageable conditions and reliance on simpler TMIs when traffic is less predictable, as with severe convective weather. Yet, the improved performance also demonstrates the benefits of TBFM's adaptive and dynamic management of arrival flows.

First, we considered arrival and airborne delays at four airports that regularly use Departure Scheduling, but rarely or never use Airborne Metering: DTW, LAS, LGA, and PHL[3]. We compared performance during hours with active use of Departure Scheduling only with that during hours without active use of TBFM at all (Table 2-2)[4]. We focused on hours when arrival demand exceeded 70 percent of the airport arrival rate and without active use of GDPs, ground stops, or Airborne Metering. Note that traffic managers typically use Departure Scheduling for DTW, LGA, and PHL when demand is high, while for LAS they use it for about 11 hours daily.

For DTW, LGA, and PHL, arrival delays vary significantly less when Departure Scheduling is actively used (Table 2-3)[5]. Average arrival delay for LAS is about 1.5 minutes greater with the same variability, but this likely reflects that Departure Scheduling is used regularly for LAS rather than as conditions warrant. At LGA, Departure Scheduling is used for many arrivals from distant airports, resulting in about 15 percent shorter airborne delay[6]. At the other three airports, there is little difference between average airborne delay with and without Departure Scheduling. For all airports, airborne delays vary less with Departure Scheduling although the difference is negligible for PHL.

Table 2-3 – Arrival and Airborne Delay With and Without Departure Scheduling

Airport	Not Departure Scheduling				Departure Scheduling			
	Arrival Delay (minutes)		Airborne Delay (minutes)		Arrival Delay (minutes)		Airborne Delay (minutes)	
	Avg.	St.Dev.	Avg.	St.Dev.	Avg.	St.Dev.	Avg.	St.Dev.
DTW	6.7	7.3	5.7	4.2	5.4 (-19%)	5.0 (-32%)	5.6 (-1.8%)	3.2 (-24%)
LAS	6.4	4.9	1.9	3.0	7.9 (+23%)	4.9 (0%)	2.0 (+0.5%)	1.8 (-40%)
LGA	6.4	7.1	6.0	5.7	5.4 (-16%)	5.0 (-30%)	5.1 (-15%)	3.4 (-40%)
PHL	7.1	8.2	5.0	3.5	5.9 (-17%)	5.6 (-32%)	4.9 (-2.0%)	3.3 (-0.6%)

Next, we considered arrival and airborne delays, and holding and vectoring in particular, at airports that regularly use Airborne Metering, and compared performance of metered flights with that of flights managed by MIT restrictions alone. We identified airports with many busy hours[7], without any GDPs or ground stops, for which either MIT restrictions alone or Airborne Metering was used to manage arrivals. We only considered airports for which 1 percent or more of the flights landing during such hours were subject to MIT restrictions alone. Also, we only considered airports whose arrivals were managed by Airborne Metering regularly in the past two years. Four airports remained good candidates for comparison: ATL, EWR, FLL, and SFO. This assessment addressed each of these airports, but did not compare them because traffic managers use TBFM differently for each. Arrivals to ATL and EWR are both metered regularly, but are handled differently. Arrivals to ATL are metered in Centers before ZTL, but not in ZTL where MIT restrictions are used. Centers adjacent to N90, except ZNY, meter arrivals to EWR. Traffic managers have regularly used TBFM to manage heavy winter traffic into FLL, but use TBFM for SFO arrivals only as conditions warrant. We compared performance between two sets of flights: those subject to MIT restrictions alone and those managed with Airborne Metering[8]. The metered flights may or may not have been subject to MIT restrictions; it is common for metered flights to be managed by MIT restrictions before entering a metering Center's airspace. The metered flights may also have been managed as scheduled departures. To eliminate irregularities associated with weather, we excluded those flights subject to MIT restrictions due to weather from both sets. We also excluded flights subject to MIT restrictions placed to manage departure flows.

Table 2-2 – Number of Hours and Average Arrival Rates for Airports that Regularly Use Departure Scheduling Without Airborne Metering

Airport	Without Departure Scheduling		With Departure Scheduling	
	Number of Hours	Avg. Hourly Rate	Number of Hours	Avg. Hourly Rate
DTW	1,718	43.7	1,867	48.3 (+5.3%)
LAS	333	32.5	2,123	31.9 (-1.8%)
LGA	3,177	25.1	7,090	32.4 (+29%)
PHL	672	34.1	1,889	38.2 (+12%)

For all four airports, we expect to see that flights managed with Airborne Metering have less airborne delay than flights subject to MIT restrictions alone and that metered flights are less likely to be subject to any holding and vectoring prior to the arrival Center.

The improved performance for flights managed with Airborne Metering is partly because of the advantages of time based flow management over distance-based flow management. However, when congestion is severe or conditions are unpredictable, traffic managers often prefer the simpler distance-based techniques to metering. To ensure that the performance differences we find are not merely because of differences in conditions, we compared arrival congestion for the two sets of flights (Fig. 2-1). In fact, we find that on average flights to EWR subject to MIT restrictions alone landed during more congested hours than those that were metered, which results in shorter delays for metered flights. However, metered flights to FLL and SFO usually landed during more congested hours. For ATL, there is no significant difference in congestion at the time of arrival between metered flights and those that are subject to MIT restrictions alone.

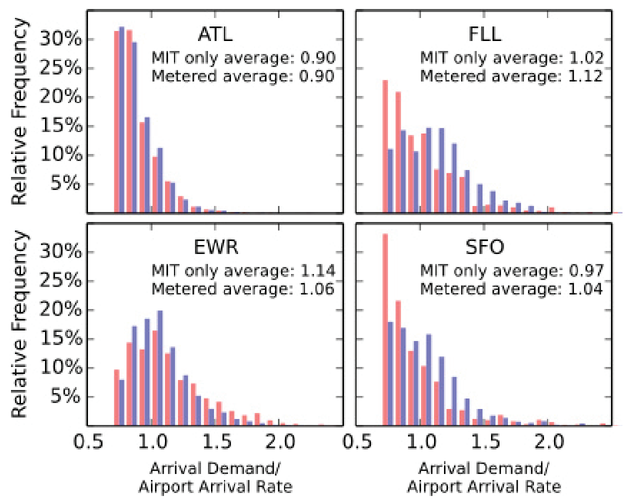


Figure 2-1 – Congestion Upon Arrival of Metered Flights and Flights Subject to MIT Restrictions Alone

Flights managed with Airborne Metering have consistently lower average arrival delays than those subject to MIT restrictions alone, but most of the arrival delay is incurred before pushback (Table 2-4)[9]. Since flights of neither set are subject to MIT restrictions for weather and the range of congestion upon their arrival is similar, the reason for the large difference in delays before pushback is unclear. It may be that when only MIT restrictions are used, such restrictions are frequently passed back to Centers from which the flights are departing, causing these flights to be delayed on the ground.

Flights metered to ATL, EWR, and SFO are also less likely to experience airborne delay. The airborne delay is smaller on average across all flights as well as among those with positive airborne delay. The differences are greater for ATL and EWR, where Airborne Metering is more regularly used.

Flights to EWR and FLL that are managed with Airborne Metering have less variable airborne delays (Fig. 2-2). Also, the metered flights to EWR, FLL, and SFO do not experience the high airborne delays seen by some flights subject to MIT restrictions alone.

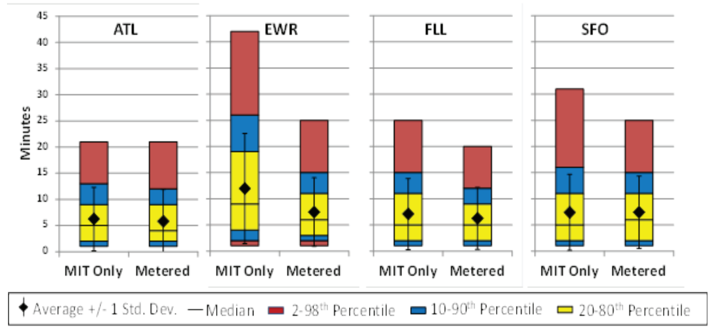


Figure 2-2 – Distribution of Airborne Delay

The difference between the airborne experiences of metered flights and those subject to MIT restrictions alone is evident in holding and vectoring as well (Fig. 2-3). Flights managed with Airborne Metering accumulate shorter holding and vectoring delays on average, and these delays are also less variable for flights to EWR and FLL.

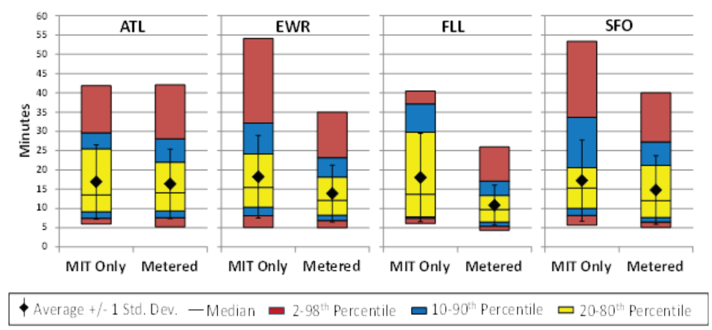


Figure 2-3 – Distribution of Holding and Vectoring Delays

Table 2-4 – ASPM Delays for MIT Only and Airborne Metered Flights

Airport		Average Arrival Delay (minutes)	Average Pushback Delay (minutes)	Average Airborne Delay (minutes)		Arrivals with Airborne Delay
				All Arrivals	Arrivals with Airborne Delay	
ATL	MIT	15.6	13.2	3.1	6.3	48.3%
	Metered	6.5 (-58%)	5.2 (-61%)	2.4 (-23%)	5.8 (-8%)	40.9%
EWR	MIT	15.9	12.8	7.4	12.0	62.2%
	Metered	7.0 (-56%)	7.7 (-40%)	3.7 (-50%)	7.5 (-38%)	49.0%
FLL	MIT	18.0	14.7	2.9	7.1	40.5%
	Metered	8.4 (-53%)	7.1 (-52%)	2.7 (-7%)	6.3 (-11%)	43.1%
SFO	MIT	15.3	15.1	3.8	7.4	51.7%
	Metered	6.9 (-55%)	6.5 (-57%)	3.7 (-3%)	7.4 (0%)	50.4%

Finally, it is also worthwhile to note differences in locations where the flights accumulate holding and vectoring delays: before the arrival airport's Center, in the arrival airport's Center, and in the arrival airport's TRACON. Consistent with the overall decrease in delay, average holding and vectoring delay in nearly all locations is shorter for flights managed by Airborne Metering (Fig. 2-4). The one exception is holding and vectoring delay of arrivals to EWR accumulated in N90, which increases slightly. Moreover, flights managed by Airborne Metering are significantly less likely to experience holding and vectoring

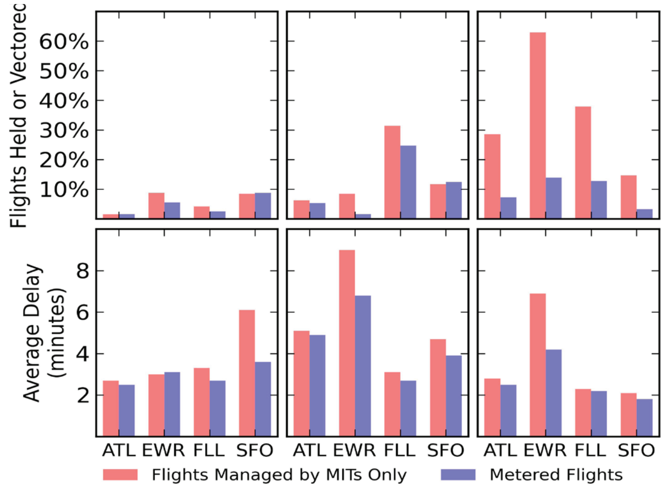


Figure 2-4 – Holding and Vectoring by Location

before the arrival Center, suggesting an absence or relaxation of MIT restrictions upstream of the arrival Center when using Airborne Metering.

CONCLUSIONS

The use of TBFM to manage arrival flows varies across facilities and fluctuates for specific airports. One common pattern is regular use of Departure Scheduling or Airborne Metering at certain times of day (e.g., CLT, EWR, LAS). Another is a tendency to use Departure Scheduling alone and then, for some airports, to include Airborne Metering as needed (e.g., BOS, DEN, IAH). For several airports with less volume in recent years, traffic managers have relied less on Airborne Metering than in the past (e.g., IAD, MEM).

For three of four airports studied that use Departure Scheduling alone, arrivals tended to experience less arrival delay, 1.0 to 1.3 minutes on average, when the facility was scheduling departures. Arrivals to LGA see nearly all of this reduction in the air, while the average airborne delay for other airports' arrivals differs by less than 0.1 minutes. Departure Scheduling also reduces the variability of delay.

Facilities have used Airborne Metering to alleviate the need for MIT restrictions. There is a large difference between the average arrival delays of metered flights and those subject to MIT restrictions alone, ranging from 8 to 10 minutes for the four airports studied. It is unclear how much of this difference can be attributed to TBFM because much of the difference occurs on the ground. However, metered flights also experience less airborne delay than those subject to MIT restrictions, with typical reductions in average airborne delay of less than a minute. Arrivals metered to EWR experience nearly four minutes less airborne delay than their counterparts subject to MIT restrictions alone. Metered flights also experience fewer extreme airborne delays and less variability in airborne delay.

The airborne delay differences between metered flights and those subject to MIT restrictions alone were reflected in holding and vectoring delays as well. In fact, we found a disproportionately greater reduction in holding and vectoring before the arrival Center for all four airports studied. It appears that flights in metered arrival flows incur less delay before the metering Center's airspace.

END NOTES:

[1]This procedure by which ATCT controllers call the ARTCC Traffic Management Unit to gain approval to release departures is known as Call for Release or APREQ.

[2]ASPM provides hourly indications of airport arrival capacities via its Airport Arrival Rates (AAR) and of arrival demand via its Terminal Arrival Efficiency Rate arrival demand. Also, it has information for individual flights about delays at various points (e.g., pushback from gate, takeoff, landing, arrival gate) and excess time spent in various phases (e.g., taxi-out, airborne, taxi-in). ASPM also indicates whether a flight was given an Estimated Departure Control Time by a GDP.

[3]While traffic managers have used Departure Scheduling for arrivals to IAD recently, only a few flights are scheduled each day.

[4]We assumed traffic managers were using Departure Scheduling during hours when at least five arrivals to the airport were scheduled by TBFM. While traffic managers use TBFM for situational awareness, this use of TBFM is not recorded.

[5]An ASPM arrival delay is the difference between a flight's actual arrival time at the gate and a nominal time based on intended departure time, the Estimated Time En Route (ETE) in the flight plan, and estimated unimpeded taxi-out and taxi-in times.

[6]ASPM airborne delay is the difference between actual airborne time and the ETE.

[7]Busy hours are the hours during which arrival demand exceeded 70 percent of the airport arrival rate.

[8]We assume flights were metered if the TBFM message set indicated that the freeze horizon was active and the meter fix times were sent to controller displays.

[9]Note that the available flight-level ASPM pushback and airborne delays have negative values rounded up to zero. Therefore, the sum of these component delays may exceed a flight's arrival delay.

AUTOMATED TERMINAL PROXIMITY ALERT

Controllers separating aircraft near airports use various radar tracking and flight data processing automation systems. The Terminal Radar Approach Control (TRACON) facilities for most major airports have either a Common Automated Radar Terminal System (CARTS) or a Standard Terminal Automation Replacement System (STARS). Although developed for use by terminal area controllers, these systems typically have displays in Air Traffic Control Towers (ATCT) that improve their staff's awareness of the incoming traffic.

The Automated Terminal Proximity Alert (ATPA)function was introduced to CARTS in 2011 and STARS in 2013[1]. ATPA assists TRACON and ATCT controllers by displaying spacing that aircraft are projected to have on their final approach course (Fig. 3-1). ATPA also projects spacing into the very near future and warns of a predicted loss of separation.

ATPA improves controllers' situational awareness, and may assist in reducing "compression errors." Compression is the natural decrease in spacing between successive aircraft on the final approach course as they decelerate from approach to landing speeds. Variability in winds and pilot and airframe performance can make the closure rate difficult to predict. A compression error is a loss of separation due to an unexpectedly high closure rate.

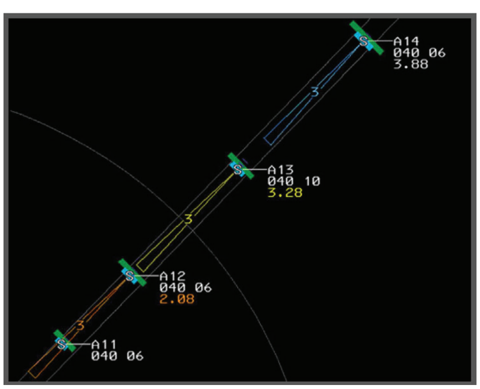


Figure 3-1 – ATPA Display

To avoid compression errors, controllers instruct pilots to make minor adjustments in speed. When these adjustments are insufficient to avoid a loss of separation, a controller instructs a pilot to "go-around" and eventually incorporates the aircraft back into an approach sequence. The enhanced situational awareness provided by ATPA may affect both the go-around rate and the spacing between flights on their final approach course. While the go-around rates due to compression errors are likely to be reduced with ATPA use, changes in spacing on final are more difficult to predict. On one hand, the information ATPA provides may give controllers the confidence to reduce spacing. Alternatively, spacing may actually increase because controllers are more aware of projected compression errors and may act more cautiously.

ATPA is an enhancement to the Terminal Proximity Alert (TPA) feature of CARTS and STARS. It is available at locations with color CARTS displays and STARS platforms. However, the feature requires controller training and software adaptation for each runway where it is to be used. As of June 2013, ATPA was adapted and in use at 28 airports in the National Airspace System (NAS) (Table 3-1). While installed at A80, ATPA is still not available for use due to its incompatibility with Atlanta airport's Precision Runway Monitor setup. In addition, it has been installed at N90 and was pending an operational assessment at the time this analysis was completed.

Table 3-1 – ATPA Availability as of June 2013

TRACON	Airports and Runways (all runways unless otherwise indicated)	Operational Use Date
C90	MDW	Apr 2012
	ORD	Oct 2011
D01	DEN	Mar 2012
M03	MEM (18LCR, 36LCR)	Jun 2013
M98	MSP	May 2011
MIA	MIA	Dec 2013
NCT	OAK (12, 28LR, 30)	Apr 2013
	RNO (16LR, 34LR)	Jan 2014
	SFO (10LR, 19LR, 28LR)	Sep 2011
	SJC	Oct 2012
	SMF	May 2013
PCT	BWI, DCA, IAD, RIC	Apr 2012
SCT	BUR (08), CRQ (24), LAX, LGB (30), MYF (28LR), NKX (24LR), ONT, PSP (31LR), SAN, SNA, VNY (16R)	May 2012
SDF	SDF (17LR, 29, 35LR)	Apr 2013
T75	STL	Jul 2011

Once ATPA is installed and ready for use, controllers are not required to use it. Since it is an advisory tool, controllers can choose whether to view its projections and warnings. Unfortunately, a consistent record of these controller settings is not available. Human factors studies and facility reports suggest that many controllers do use ATPA's numerical indicator of spacing on final, while the use of graphical indicators is less common [2-5].

Table 3-2 – Airports and Runways Likely Affected by ATPA

Airport	Runways
BWI	10 and 33L
DEN	16L*, 35L*, and 35R*
IAD	01C, 01R, 19L*, and 19C
LAX	24R* and 25L*
MDW	04R, 22L, and 31C
MEM	18L, 18R, 36L, and 36R*
MSP	12L, 12R, 30L, 30R, and 35*
ORD	27L*, 27R*, and 28R
SAN	27
SDF	17L, 17R, 35L, and 35R
SFO	28L and 28R

*Runways that are usually dedicated to arrivals and are independent of other operations at the airport.

Operational impact analysis of ATPA use requires trajectory and final approach spacing data. We used MITRE's Threaded Track data base, a fusion of National Offload Program, Airport Surface Detection Equipment Model X, and Traffic Flow Management System data. The Threaded Track data contain smooth aircraft trajectories, and is available for flights that filed instrument flight plans starting in August 2010.

Final approach spacing data contain pairs of successive approaches to the same runway and the spacing between them at various positions along the final approach course. These data also help identify the flights that aborted their approaches and the location where they started deviating from their normal descents.

In the absence of direct observation of controller use of ATPA, this assessment addresses the operational effects of the *availability* of ATPA. We investigated changes in go-around rates and final approach spacing before and after ATPA became available at 11 airports with regularly high volumes of traffic, but without too much Visual Flight Rules traffic (Table 3-2). Our analysis excludes airports where arrival demand consistently remains below 70 percent of airport arrival rates (more than 99 percent of the time in 2013). It also focused on runways that were mainly dedicated to arrivals conducted independently of other operations at the airport. Finally, to complement our empirical analysis and findings, we also discuss the key controller inputs that were collected during the post-implementation human factors analysis [2-5].

OPERATIONAL PERFORMANCE ASSESSMENT

IMPACT ON FINAL APPROACH SPACING

ATPA improves controllers' awareness of actual and projected spacing on final approach. This study investigated whether that improved awareness affected spacing on final for nine of the ten independent, arrivals-only runways. We excluded runway 36R at MEM from our analysis because spacing on final to this runway was also impacted by the recent implementation of new wake categorization groups and separation standards.

Of the many factors that may influence spacing on final, this study accounted for two key factors that are easily identifiable using empirical data. The first is the combination of wake classes for successive aircraft on final approach. Pilots maintaining visual separation from a larger leading aircraft will allow extra spacing to avoid encounters with wake turbulence, as will controllers when providing radar separation

Arrival demand is another factor which may influence excess spacing on final. To a point, we expect excess spacing to decline during periods of high demand. This relationship can be investigated by observing the changes in arrival pressure behind a flight, evaluated as the number of landings in the 15 minutes following its own landing (Fig. 3-2).

While the differences in arrival pressure before and after ATPA implementation may appear insignificant, they are important. Excess spacing and arrival pressure are strongly correlated (Fig. 3-3). For each additional landing in the 15 minutes following a flight's landing, the median excess spacing to its lead is a few tenths of a nautical mile shorter. For the same arrival pressure, excess spacing is generally longer after ATPA implementation for

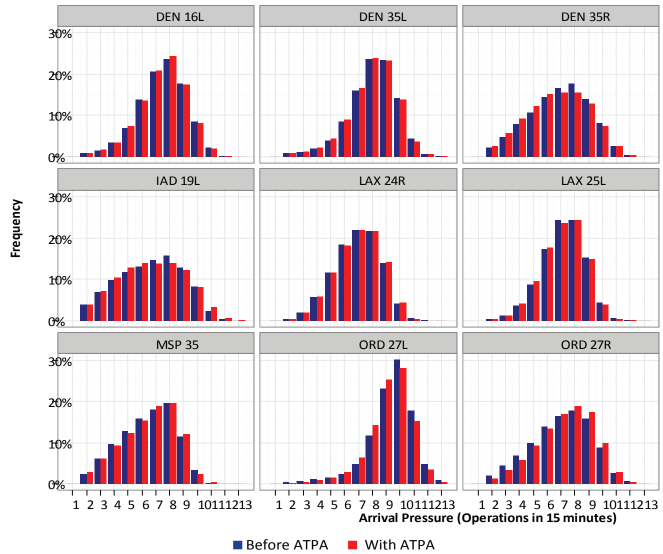


Figure 3-2 – Distribution of Arrival Pressure by Runway

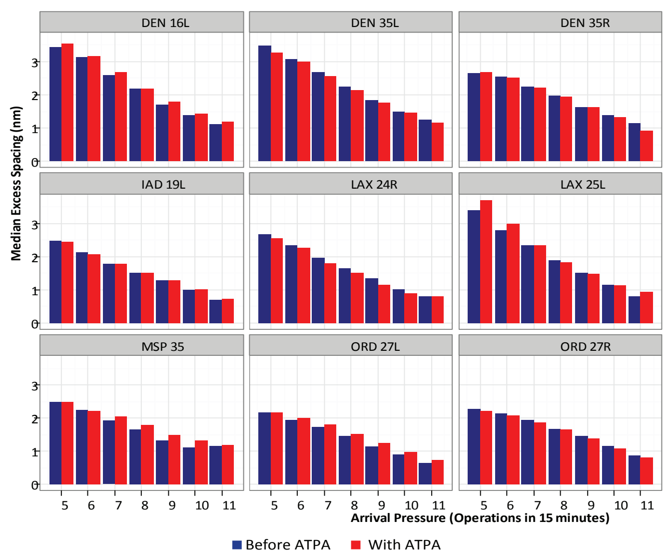


Figure 3-3 – Relationship Between Excess Spacing and Arrival Pressure

DEN 16L, MSP 35 and ORD 27L, while it is generally shorter for DEN 35L and 35R, LAX 24R and ORD 27R[1].

Since ATPA use is likely to create more significant impacts during periods of high demand, we narrowed our focus to flights with substantial arrival pressure – those with five or more followers in the 15 minutes after landing. For most runways, as expected, an increase in median arrival pressure generally results in shorter median excess spacing (Table 3-3). DEN 35L and 35R are exceptions, with a decrease in excess spacing despite a reduction in arrival pressure. Note that ATPA is only one factor contributing to these changes; for instance, shortly after ATPA implementation, ORD 27R was approved for reduced radar separation.

Also, note that median excess spacing for DEN 35L, DEN 35R, and LAX 24R decreased significantly despite flat or lower arrival pressure. At LAX, ATPA assists merging by reducing uncertainty about whether gaps can accommodate insertions, a previously unanticipated mechanism[2]. At DEN, the same benefit may apply when arrivals land only on Runways 35L and 35R: both of these arrival streams include merging onto the final approach courses.

Table 3-3 – Changes in Arrival Pressure and Excess Spacing after ATPA Implementation*

Runway	Median Arrival Pressure (landings)	Median Excess Spacing (nm)	Excess Spacing for the Same Arrival Pressure
DEN 16L	-0.02	+0.06	Increase
DEN 35L	-0.06	-0.08	Decrease
DEN 35R	-0.11	-0.05	Decrease
IAD 19L	-0.06	0.00	Same
LAX 24R	+0.01	-0.15	Decrease
LAX 25L	-0.04	+0.02	Same
MSP 35	0.00	+0.09	Increase
ORD 27L	-0.22	+0.14	Increase
ORD 27R	+0.11	-0.08	Decrease

* For arrivals with five or more landings in the 15 minutes following landing.

IMPACT ON GO-AROUNDS

There are many reasons for a controller or pilot to decide to terminate a flight's approach. Common reasons include the pilot not having the runway in sight, the approach not being stabilized[3], unacceptable runway conditions, and an imminent compression error. The last of these may become less frequent with the improved situational awareness ATPA provides. This potential impact was investigated by evaluating changes in two metrics: go-around rates and distance-to-lead when go-arounds started. The first metric was evaluated for each airport and the second for each of the runways considered in the spacing analysis.

We evaluated daily go-around rates for each of the runways that were adapted for ATPA use, before and after it became operational[4]. The rate is volatile even when summarized monthly (Fig. 3-4). Occasionally, a number of go-arounds can happen over a short period of time because of extreme weather or runway conditions. Since such outliers are likely unrelated to ATPA use, we excluded days for which the go-around rate was greater than 95 percent of all the rates.

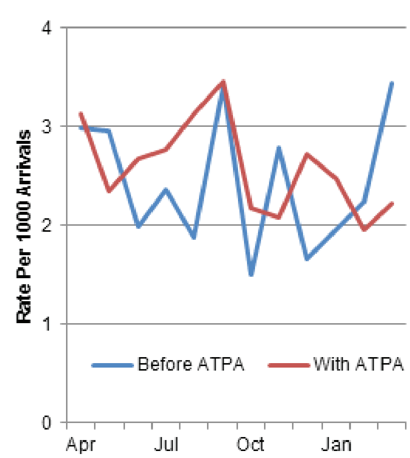


Figure 3-4 – Average Monthly Go-Around Rates Example: BWI

We found no statistically significant difference in daily go-around rates for the following eight airports: BWI, DEN, IAD, LAX, MSP, ORD, SAN, and SDF. For the remaining three airports, although there was a statistically significant increase in the average daily go-around rates, other extraneous factors may have played a more significant role than ATPA:

- At MEM, go-around rates started increasing near the implementation of RNAV STARs with Optimized Profile Descents in July 2012 and wake recategorization separation standards in November 2012. Go-around rates continued to increase even after ATPA became operationally available in June 2013.
- At SFO, after ATPA became operational, Runways 28L and 28R were closed intermittently during weekends. The weekend go-around rate in this period (3.9 per 1,000 arrivals) matched that of the period before it became operational (3.8 per 1,000 arrivals) when all runways were open, but was higher (6.0 per 1,000 arrivals) when the runways were closed.
- At MDW, the increase in go-around rates was minor. When a few days with several go-arounds in November 2013 were excluded from the analysis, the increase in the average rate became insignificant.

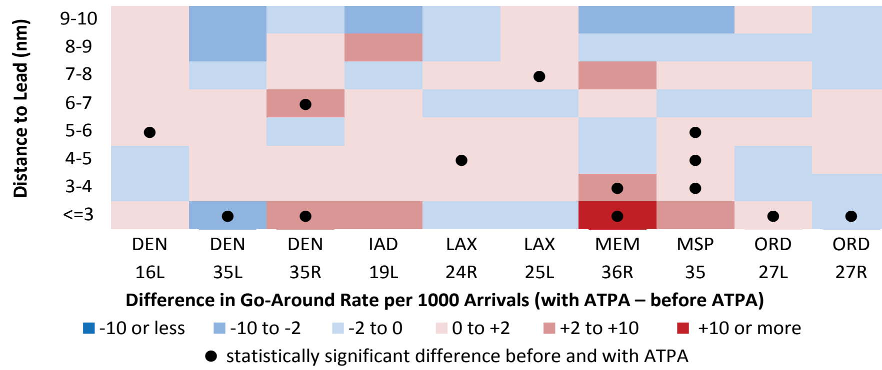


Figure 3-6 – Differences in Locations Where Flights Initiate Go-Arounds

ATPA's display of actual and projected spacing may influence where controllers instruct pilots to initiate a go-around. ATPA may cause go-arounds to occur later because controllers now have a more accurate understanding of actual spacing and projected violations, and may wait a bit longer before terminating an approach that is closing in on its lead. However, ATPA may cause go-arounds to occur earlier because the information provided could alert controllers to situations requiring a go-around sooner.

To investigate such potential impacts, we considered the location of an aircraft initiating a go-around and its distance to the lead aircraft at the time[5]. We did so for arrivals to the 10 runways identified previously where go-arounds would not be caused by operations other than the leading arrival. Not surprisingly, the go-around rate is typically higher for flights that got within 3 nm of their leading flights (Fig. 3-5). This was true for all runways, although less pronounced for ORD 27L.

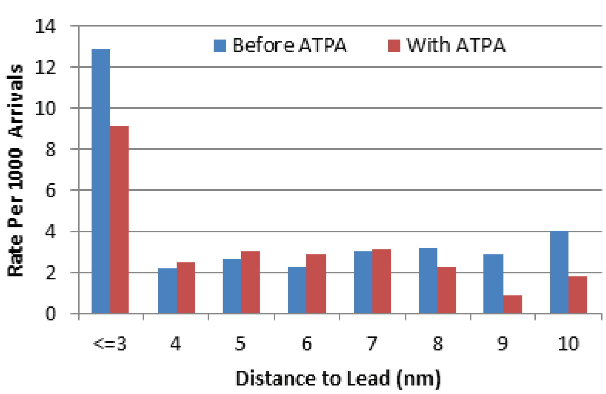


Figure 3-5 – Go-Around Rate by Closest Distance to Lead

While we observed some significant differences in distance from lead at the moment when a go-around was initiated, we found no consistent pattern (Fig. 3-6). Moreover, the differences for flights that were closest to their lead at the time they executed the go-around were mixed and inconclusive.

While the empirical data suggest no significant impacts of ATPA on spacing efficiency and go-around rates, other benefits are noteworthy. First, ATPA has automated features that do not require controllers' time and attention previously used to manually invoke similar information. [1] Also, post-implementation surveys report that the majority of controllers regularly use ATPA to assist in monitoring final separation, and find it easy to use and beneficial [2-5]. Most cite improved situation awareness, and attribute it to the spacing information ATPA provides in the flight data block. This enhanced awareness is likely to be especially useful at MEM and SDF, where separation standards have recently changed with wake class re-categorization.

CONCLUSIONS

Although ATPA improves controllers' awareness of the spacing between an aircraft on final approach and its leading aircraft, how and if they use the tool is hard to discern. The availability of information about measured and projected spacing may influence that spacing. This assessment considered the differences in arrival spacing before and after ATPA was implemented for nine runways frequently dedicated to arrivals and independent of other operations on other runways. The differences in median excess spacing, relative to radar and wake separation standards, ranged from -0.15 nm to 0.14 nm. The differences are mainly attributable to differences in demand as there is a strong relationship between excess spacing and the pressure to land arrivals waiting in the pattern. For several runways where heavy merging of flows occurs near the runway, a slight change in this relationship towards less excess spacing may be attributable to ATPA.

ATPA also may affect the rate and nature of go-arounds, which are sometimes triggered by anticipated loss of separation due to compression. However, go-arounds are rare events and have many causes other than anticipated loss of separation. For eight of 11 airports assessed, we found no significant difference in the overall go-around rate before and after ATPA implementation. At the remaining three airports, increases in go-around rates were either very small or likely caused by other factors. Furthermore, this assessment found no consistent change in the distance to leading flights when go-arounds started.

Since ATPA is an advisory tool, its varied use from site to site comes as no surprise. However, despite these inconclusive quantitative results, ATPA has gained a highly favorable rating from controllers. At five facilities that participated in post-implementation assessments of human factors-related impacts, a majority of the controllers reported that they regularly used ATPA because it was easy to use and beneficial. ATPA frees controllers from having to manually invoke software features to display spacing information. Controllers report that having this information available automatically improves situational awareness as they manage arrivals on final approach. This tool is thus likely to facilitate the introduction of new wake turbulence mitigation concepts and to enhance their effectiveness.

REFERENCES

[1] "Automated Terminal Proximity Alert (ATPA) – Including Enhanced TPA and Distance Processing – Air Traffic User Guide (Version 1.4)", ATPA Work Group and Terminal Field Operational Support (William J. Hughes Technical Center), May 2012.

[2] "Automated Terminal Proximity Alert (ATPA) Pre- and Post-Implementation Human Factors Analysis for Chicago O'Hare TRACON", Human Solutions, Incorporated, October 2012.

[3] "Automated Terminal Proximity Alert (ATPA) Pre- and Post-Implementation Human Factors Analysis for Minneapolis TRACON", Human Solutions, Incorporated, October 2012.

[4] "Automated Terminal Proximity Alert (ATPA) Pre- and Post-Implementation Human Factors Analysis for St. Louis TRACON", Human Solutions, Incorporated, October 2012.

[5] "Automated Terminal Proximity Alert (ATPA) Pre- and Post-Implementation Human Factors Analysis for Southern California TRACON – Quick Look Report", Human Solutions, Incorporated, October 2012.

ENDNOTES

[1] All observations are statistically significant.

[2] At LAX, both Runways 24R and 25L have straight-in arrival streams from the east and gaps in both streams are filled with arrivals from other streams (from the north for Runway 24R and from the south for Runway 25L). The runways have similar arrival pressure (Fig. 3-2), but Runway 24R generally has smaller median excess spacing (Table 3-3). The reason is a much heavier arrival stream from the north than from the south, providing a denser supply of arrivals to fill gaps in the straight-in stream.

[3] There are a variety of definitions of "stabilized approach," but the criteria typically speak to the aircraft's path, heading, pitch, speed, descent rate, power setting, and landing configuration and require that minimal adjustment is necessary to stay within operating parameters for landing.

[4] For most airports, we evaluated 12 months before and after ATPA implementation. For a few, data availability allowed only six-month periods: MEM, MSP, and SDF.

[5] The initiation of the go-around was defined as the track point where the permanent deviation from the final approach course or glide slope started.

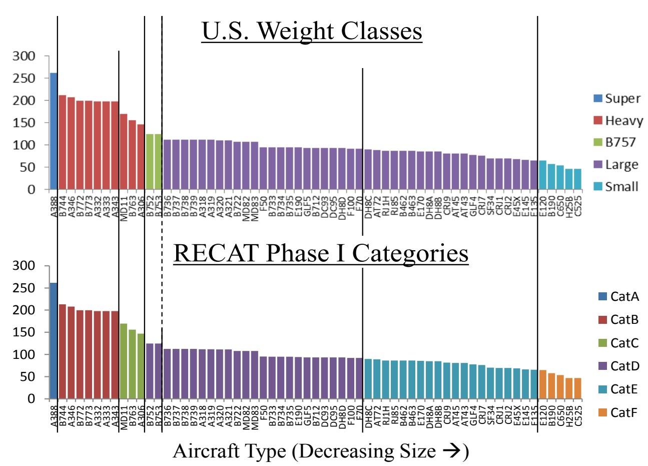

American
American Eagle

RECATEGORIZATION OF WAKE TURBULENCE CATEGORIES AT LOUISVILLE INTERNATIONAL AIRPORT

Currently, the FAA classifies aircraft for wake turbulence purposes based on maximum certified takeoff weight, creating four weight classes of heavy, Boeing 757, large and small. Although the traditional categories were modified to include Airbus 380, these categories are still not adequate and often result in longer than necessary separation distances between aircraft, particularly for models belonging to the traditional heavy class. Following more than a decade of research conducted by the FAA, NASA, EUROCONTROL, ICAO, and their industry partners, the FAA developed new aircraft classes and spacing criteria based on aircraft wingspan, certified takeoff weight and ability to withstand a wake encounter.

This Recategorization (RECAT) of Wake Turbulence Separation Categories produced six categories, labeled A through F (Fig. 4-1), and is fully detailed in FAA Order JO 7110.659A, *Wake Turbulence Recategorization*, dated June 1, 2014 [1]. In this document, the FAA describes the key differences between the categorization schemes and provides guidance for the use of the new standards. Minimum radar separations in the terminal area were not changed with this Order. The color-coding used in the RECAT table in Fig. 4-1 indicates a direction of change in separations for aircraft pairs as follows: white indicates no change, blue a decrease, and green an increase in separations. In addition, partial color-coding indicates a change for some aircraft pairs within the category, and full color-coding a change for all aircraft pairs within the category.

Compared to the traditional categorization, the narrower categories of wake RECAT provide for less variation in aircraft weight, speed and wake characteristics among the aircraft belonging to the same category. As a result, separation standards between successive aircraft can now be safely reduced for many of the same aircraft-pair combinations.



Current Weight Classes

		Follower				
		A380	Heavy	B757	Large	Small
Leader	A380	MRS	6.0	6.0	7.0	7.0
	Heavy	MRS	4.0	5.0	5.0	6.0
	B757	MRS	4.0	4.0	4.0	5.0
	Large	MRS	MRS	MRS	MRS	4.0
	Small	MRS	MRS	MRS	MRS	MRS

RECAT Phase I Categories

		7110.659A, Tbl 5-5-2, RECAT Matrix					
		Follower					
		A	B	C	D	E	F
Leader	A	MRS	5.0	6.0	7.0	7.0	8.0
	B	MRS	3.0	4.0	5.0	5.0	7.0
	C	MRS	MRS	MRS	3.5	3.5	6.0
	D	MRS	MRS	MRS	MRS	MRS	5.0
	E	MRS	MRS	MRS	MRS	MRS	4.0
	F	MRS	MRS	MRS	MRS	MRS	MRS

No Change
Separation Decrease for Entire Category
Separation Decrease for Part of Category
Separation Increase for Entire Category
Separation Increase for Part of Category

Figure 4-1 – Current and RECAT Aircraft Classes and Separation Standards (nm)

At Memphis (MEM), Louisville (SDF) and Cincinnati (CVG) airports, aircraft are now grouped into the six RECAT categories for both arrival and departure separation, beginning in November 2012, September 2013, and March 2014, respectively [2]. The FAA also implemented RECAT at Atlanta Terminal Radar Approach Control (TRACON) on June 1, 2014, and plans to expand its use to other locations in 2014.

For this analysis, we investigated the performance impacts of wake RECAT at SDF on airport and surface efficiency, for both arriving and departing flights. To account for seasonal effects and to control for operating conditions, we based our analysis on as much data as was available for the same time periods before and after RECAT implementation.

To evaluate impacts on airport efficiency, we compared arrival and departure rates observed between October 1, 2012 and January 31, 2013 (before RECAT) to those observed between October 1, 2013 and January 31, 2014 (after RECAT), as recorded in the Aviation System Performance Metrics (ASPM) database.

To evaluate impacts on surface efficiency, we examined taxi-out times in conjunction with inter-arrival and inter-departure times observed between September 10, 2012 and January 31, 2013 (before RECAT) and between September 10, 2013 and January 31, 2014 (after RECAT), using surface surveillance data.

OPERATIONAL PERFORMANCE ASSESSMENT

Changes in airport capacity are difficult to evaluate in the real world due to their sensitivity to dynamic operating conditions including weather, runway configuration, and fluctuating demand. To overcome these challenges and facilitate understanding of capacity-related changes across NAS airports, the FAA typically uses Airport Departure and Arrival Rates (ADR and AAR). These rates, also referred to as the *called* rates, are determined by the airport facilities as the number of arrivals and departures that each facility can handle for each hour of each day, based on the expected operating conditions including weather, demand characteristics, and ATC staffing.

Under these conditions, ADRs and AARs are subjective measures to some extent. However, since the facilities consider the impacts of any disturbances (e.g., runway construction projects) or new capabilities (e.g., Converging Runway Decision Aid) may have on their ability to handle traffic flows, these empirical rates can provide valuable information about changes in airport capacity over time.

Compared to the same period from the previous year, average ADR has *increased* by 4.5 percent and average AAR has not changed significantly following RECAT implementation (Fig. 4-2). However, during Instrument Meteorological Conditions (IMC), average AAR has *increased* by 3 percent and the high-end AARs (45 arrivals/hour or higher) were used 18 percent more often. More dramatically, average ADR has *increased* by 6 percent during IMC and the high-end ADRs (45 departures/hour or higher) were used 25 percent more often. Combining these rates, the facility set high-end airport rates of 90 operations

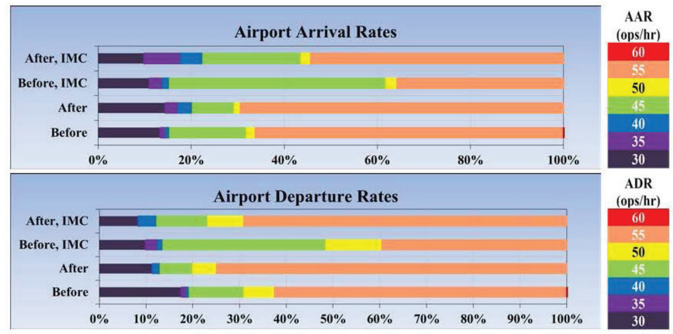


Figure 4-2 – SDF: Airport Arrival and Departure Rates

per hour or higher about 72 percent of the time overall and 68 percent of the time in IMC. Compared with the same period in the previous year, this translates into an improvement of 4 and 18 percent, respectively. Clearly, increases in the use of high-end rates resulted in improving average rates.

Unlike airport capacity, airport throughput can be more easily analyzed by directly examining hourly arrival and departure operations. Compared to the same period from the previous year, the hourly demand for both arrivals and departures has stayed relatively unchanged following RECAT implementation (Fig. 4-3).

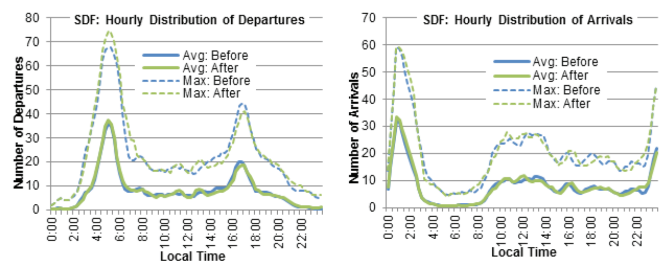


Figure 4-3 – SDF: Distribution of Airport Operations by Hour of Day

However, during that same period, there was an increase of 1 percent in overall demand and no significant change in IMC occurrence. More significantly, typical peak demand – evaluated as average hourly throughput rate – increased by 4 percent during peak arrival periods (2300-0300 local) and by 5 percent during peak departure periods (0300-0700 local). In addition, during IMC, peak departure throughput increased by 13 percent while the peak arrival throughput decreased by 6 percent. Clearly, controllers took advantage of the reduced separations and clustered aircraft closer to each other, resulting in higher peak airport throughput, with the most significant increase realized for departures during IMC.

This observed improvement in airport efficiency was driven by tighter aircraft sequences after RECAT was implemented. The distributions of inter-aircraft spacing shifted to the left (lower) for both arrivals and departures. Compared to before RECAT implementation, arrivals are now about 4 percent and departures 7 percent closer to each other on average as they land on and depart from the same runways (Fig. 4-4).

The distributions of inter-aircraft spacing shifted to the left (lower) even more when observed during peak departure periods.

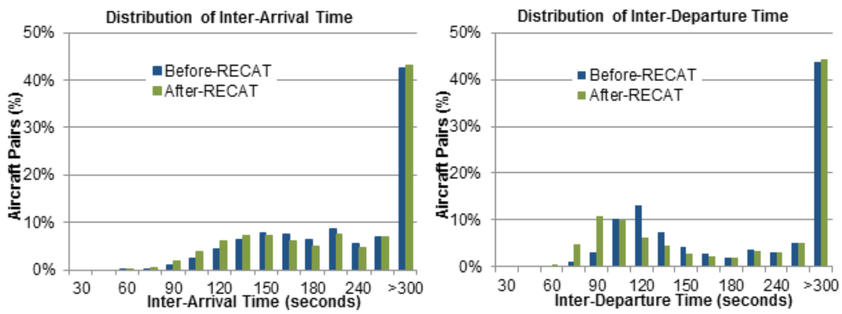


Figure 4-4 – Distribution of Inter-Aircraft Times at SDF Before and After RECAT implementation

Arrivals are now about 4 percent and departures 9 percent closer to each other on average as they land and depart from the same runways during peak periods (Fig. 4-5). These improvements in airport efficiency provided for further improvements in flight efficiency, with UPS reporting up to 53,000 lbs. of fuel savings per night [3].

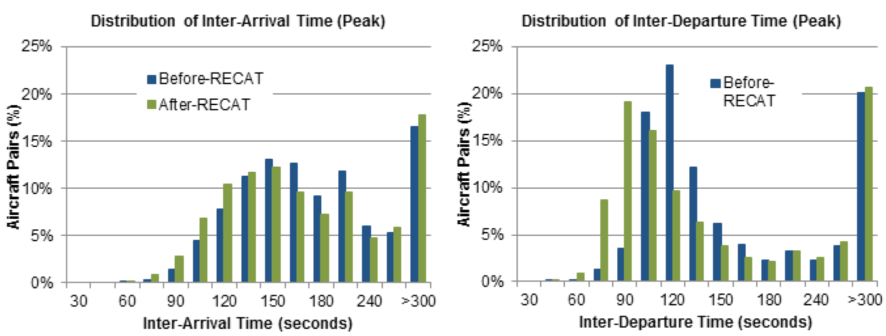


Figure 4-5 – Distribution of Inter-Aircraft Time During Peak Times at SDF Before and After RECAT Implementation

Note that reduced inter-aircraft spacing is a primary operational performance impact resulting from RECAT implementation that directly captures actual benefits from reduced separations between the same aircraft types. However, it does not address actual system and user efficiency gains. System and user efficiency-related changes in performance outcomes are considered secondary impacts, simply because they are a result of the reduced inter-aircraft spacing.

In addition, even though airport throughput and inter-aircraft spacing are related, they are not equivalent metrics. Hourly airport throughput is predominantly driven by the demand for services, and is constrained by separation standards only when demand reaches or exceeds airport capacity. Inter-aircraft spacing, on the other hand, is constrained by both the demand and the required separation standards at all times. Therefore, in some operational performance assessments, it is not redundant but rather critical to investigate both of the metrics to gain full understanding of corresponding performance impacts.

Turning our attention onto surface efficiency, departures experienced significant improvement in efficiency while on the ground. The distributions of taxi-out times for departures shifted to the left (lower) for all departures throughout the day (Fig. 4-6). Taxi-out times have decreased by over 48 seconds on average (a 14 percent reduction). Taxi-out times during peak periods decreased even more, by 1.7 minutes on average or 24 percent. This observation again highlights that controllers are taking advantage of the reduced separations and are clustering aircraft closer to each other, resulting in improved efficiency of surface operations.

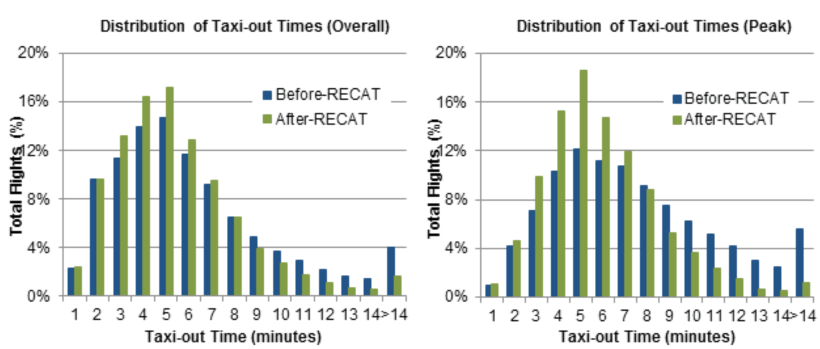


Figure 4-6 – SDF Departures: Surface Flight Efficiency Outcomes

CONCLUSIONS

The use of new Recategorization (RECAT) of Wake Turbulence Separation Categories at Louisville International Airport (SDF) began in November 2013 and resulted in increased airport capacity and throughput, and reduced taxi-out times, with the most significant improvements observed during peak periods and IMC.

During the first four months of RECAT use, the facility set high-end airport rates at 90 operations/hour or higher about 4 percent more frequently over all weather conditions, and 18 percent more frequently in IMC. During IMC, average AARs have increased 3 percent and the high-end AARs (45 arrivals/hour or higher) were used 18 percent more often. On the other hand, ADRs have increased 6 percent during IMC and the high-end ADRs (45 departures/hour or higher) were used 25 percent more often.

Compared to the previous year, SDF experienced a slight increase of 1 percent in demand and no change in IMC occurrence during the first four months of RECAT use. Typical demand increased 4 percent during peak arrival and 5 percent during peak departure periods. In addition, departure throughput increased 13 percent during the peak periods that happened in IMC while the arrival throughput decreased 6 percent. Clearly, SDF realized an improvement in airport efficiency during peak periods since controllers are taking advantage of the reduced separations and clustering aircraft closer to each other. As a result, airport throughput during peak periods improved, with the most significant improvement for departures realized during IMC.

The observed improvement in airport efficiency was driven by tighter aircraft sequences after RECAT was deployed. Departures are 7 percent closer to each other as they take off from the same runways and 9 percent closer during peak departure periods. Arrivals are now about 4 percent closer to each other as they land on the same runways during all times, including peak arrival periods. Improved airport efficiency provided for further improvements in flight efficiency, with UPS reporting up to 53,000 lbs. of fuel savings per night.
Departures experienced significant improvement in efficiency of their surface operations. Compared to before RECAT implementation, taxi-out times have decreased by over 48 seconds on average (a 14 percent reduction). During peak departure periods, taxi-out times have decreased by 1.7 minutes on average or 24 percent. Once again, controllers are taking advantage of the reduced separations and clustering aircraft closer to each other, which results in improved efficiency of surface operations.

REFERENCES

[1] FAA, June 2014, Order 7110.659A, *Wake Turbulence Recategorization,* URL: http://www.faa.gov/documentLibrary/media/Order/7110.659A.pdf
[2] FAA, September 2013, NextGen Operational Performance Assessment, pages 39-44, URL: http://www.faa.gov/nextgen/media/NGOPA_2013.pdf
[3] Air Traffic Procedures Advisory Committee, December 2013, Notes from the 147th Meeting, URL: http://www.faa.gov/about/office_org/headquarters_offices/ato/service_units/systemops/atpac/media/ATPAC_Minutes_147.pdf

DEPENDENT APPROACHES TO CLOSELY SPACED PARALLEL RUNWAYS AT SAN FRANCISCO INTERNATIONAL AIRPORT

FAA Order 7110.65, commonly known as the Air Traffic Control Manual, limits the use of dependent instrument approaches to parallel runways with centerline spacing of at least 2,500 ft. In November 2008, the FAA first published Order 7110.308, allowing dependent instrument approaches to specific parallel runways with centerline spacing of less than 2,500 ft., known as Closely Spaced Parallel Runways (CSPR). In October 2012, we updated the Order to allow dependent instrument approaches at additional airports and runways, including Runways 28L/R at San Francisco International Airport (SFO) [1]. Because of a runway construction project during which ILS 28L was out of service, operational use of the Order at SFO did not start until September 2013.

The use of dependent instrument approaches enables effective capacity gains at SFO during operating conditions when only single runway approaches were possible in the past. The new dependent instrument approaches can be conducted if the lead aircraft belongs to a small or large wake class, lands on 28L, and has at least 1.5 nm diagonal separation from the trailing paired aircraft (Fig. 5-1). This procedure does not require any specific aircraft equipment or performance capabilities.

At SFO, controllers can also use Simultaneous Offset Instrument Approach (SOIA) procedures during some of the same conditions. SOIA requires a minimum cloud ceiling of 2,100 ft. and visibility of 4 statute miles, and uses a straight-in course to one of the runways while the other course is offset by 2.5 to 3 degrees. Although it provides a greater capacity potential than dependent instrument approaches enabled by Order 7110.308, SOIA also requires use of Precision Runway Monitor and additional controller positions. As a result, dependent instrument approaches are likely the best alternative during times when CAT I operations or better are possible and demand does not exceed capacity enabled by Order 7110.308.

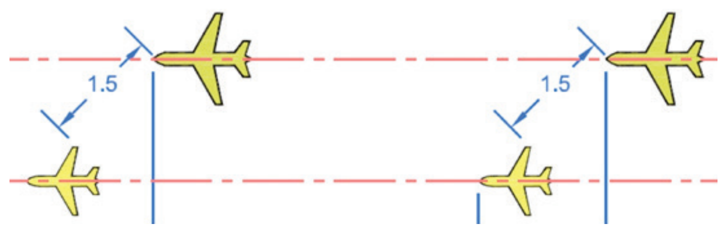


Figure 5-1– Staggered CSPR Operations at San Francisco International Airport

OPERATIONAL PERFORMANCE ASSESSMENT

To study operational and performance impacts of dependent approaches to CSPRs at SFO, we investigated changes in airport and flight efficiency. For the airport efficiency analysis, we analyzed Aviation System Performance Metrics (ASPM), and compared arrival and departure capacity and throughput between October 1, 2012 and January 31, 2013 (pre-implementation time period) to those observed between October 1, 2013 and January 31, 2014 (post-implementation time period). Since visual approaches at SFO are not affected by Order 7110.308, we focused on changes in performance outcomes observed during IMC.

Compared to the same period from the year before, arrival and departure demand was about 4 percent higher during the first four months after initiation of CSPR operations at SFO (Fig. 5-2). SFO has a history of weather related delay problems due to the combination of its runway configuration and local weather patterns. Marine climate makes low ceilings/visibility frequent and unpredictable, and can cause significant delays when scheduled arrivals exceed bad weather runway capacity. IMC occurrence decreased from 24 percent during pre-implementation to 16 percent during post-implementation periods.

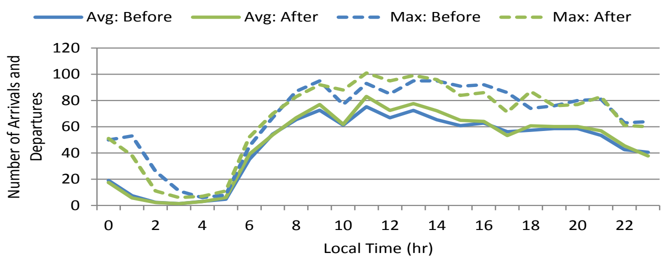


Figure 5-2—Arrival and Departure Throughput at San Francisco International Airport

Typically, the FAA uses Airport Departure and Arrival Rates (ADR and AAR, respectively) to facilitate understanding of capacity related changes across NAS airports. These rates, also referred to as the called rates, are set by the airport facilities as the number of arrivals and departures that each facility can handle for each hour of each day, based on the expected operating conditions including weather, demand characteristics, and ATC staffing. Clearly, ADRs and AARs are subjective measures; however, since the facilities consider the impacts any disturbances (e.g., runway construction projects) or new capabilities may have on their ability to handle traffic flows, these empirical rates provide valuable information about changes in capacity over time.

During the first four months after initiation of dependent approaches to CSPRs at SFO, average ADR and AAR have increased by 5 percent and 13 percent during IMC. This increase was not driven by a significant increase in maximum rates, but rather by an 11 percent more frequent use of the high-end rates, including ADR of 50 or more departures per hour, AAR of 50 or more arrivals per hour, and the combined rate of 100 or more aircraft per hour.

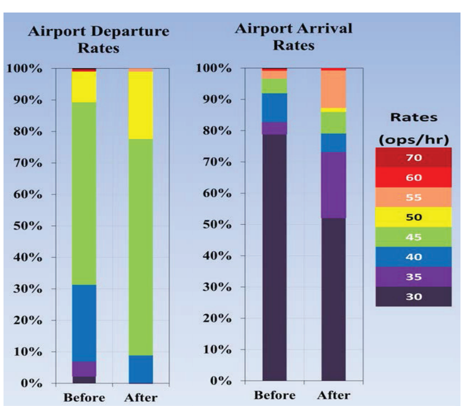


Figure 5-3—Airport Arrival and Departure Rates during IMC at San Francisco International Airport

Prior to dependent approaches to CSPRs at SFO, flights were forced to use a single approach stream during periods of low visibility below SOIA minimums, limiting the airport's arrival rate to approximately 30 per hour and often requiring a Ground Delay Program. Since initiation of dependent approaches, the use of AARs of up to 30 arrivals per hour has decreased from 47 to 33 percent of the time over all conditions, and from 79 to 52 percent of the time in IMC (Fig. 5-3). More importantly, rates of 35 arrivals per hour are now used significantly more frequently in IMC, often enabled by the use of dependent approaches.

Attributing improvements in airport capacity and throughput to the ability to use dual CSPR approaches at SFO was complicated by a 4 percent increase in demand occurring simultaneously with a decrease in IMC from 24 percent to 16 percent of the time. However, throughput increased by 8 percent for both arrivals and departures during the same conditions after introduction of CSPR approaches (Fig. 5-4).

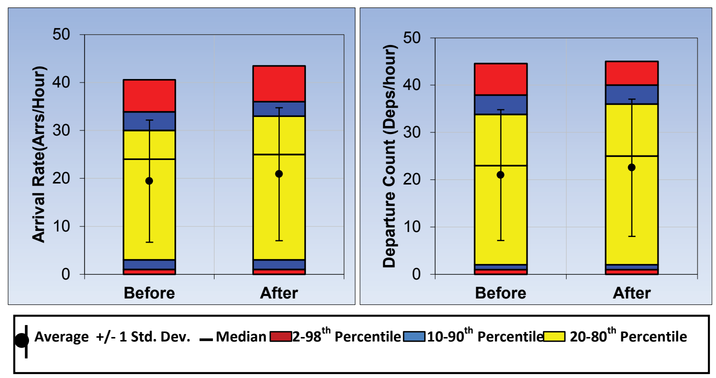


Figure 5-4—Hourly Arrival and Departure Throughput during IMC

To analyze the impact on surface operations, we used the Airline Service Quality Performance subset of ASPM data, and determined that taxi-in times did not change significantly, while the taxi-out times are now about 4 percent shorter. Taxi-in and taxi-out delays, however, are now both lower by about 10 percent and 26 percent, respectively.

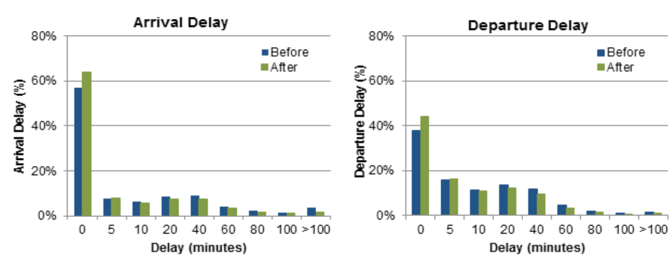


Figure 5-5—Arrival and Departure Delays at San Francisco International Airport

Although the new dual approaches to CSPRs at SFO directly impact arriving flights, they may cause changes in performance of both arrivals and departures. Since taxiways and runways are shared between arriving and departing aircraft, a change in arriving flows is likely to spill over onto departures too. Therefore, we investigated changes in departure and arrival delays and determined that their distributions shifted to the left (Fig. 5-5). Average arrival and departure delays are now five and two minutes shorter, a reduction of 33 percent and 20 percent, respectively.

CONCLUSIONS

In October 2012, the FAA approved dependent approach operations for SFO's closely spaced parallel runways 28L/R. Because of a runway construction project during which ILS 28L was out of service, operational use of dependent approaches at SFO did not start until September 2013. The use of dependent instrument approaches enables effective capacity gains at SFO during operating conditions when only single runway approaches were possible in the past, including frequent low ceiling and visibility conditions.

Attributing improvements in airport capacity and throughput to the ability to use dual CSPR approaches at SFO was complicated by a simultaneous increase in demand and a decrease in IMC occurrence. Nevertheless, during the first four months after initiation of dependent approaches to CSPRs at SFO, average arrival and departure throughput each increased by 8 percent. Average AAR and ADR increased 13 percent and 5 percent during IMC, predominantly driven by an 11 percent more frequent use of the high-end rates. This increase in effective capacity and throughput further contributed to a reduction in taxi, departure, and arrival delays at SFO.

REFERENCES

[1] FAA Order 7110.308, URL: http://www.faa.gov/documentLibrary/media/Order/JO%207110.308.pdf

ACRONYMS

AAR	Airport Arrival Rate
ACM	Adjacent Center Metering
ADR	Airport Departure Rate
ARTCC	Air Route Traffic Control Center
ASDE-X	Airport Surface Detection Equipment–Model X
ASPM	Aviation System Performance Metrics
ATC	Air Traffic Control
ATCT	Air Traffic Control Tower
ATPA	Automated Terminal Proximity Alert
CARTS	Common Automated Radar Terminal System
CAT	Category
CSPR	Closely Spaced Parallel Runways
EDC	En Route Departure Capability
ELSO	Equivalent Lateral Spacing Operation
ERAM	En Route Automation Modernization
ETE	Estimated Time En Route
EUROCONTROL	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FY	Fiscal Year
GCD	Great Circle Distance
GDP	Ground Delay Program
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
ILS	Instrument Landing System
IMC	Instrument Meteorological Conditions
MIT	Miles-in-Trail
MON	Minimum Operational Network
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NAVAID	Navigational Aid
NextGen	Next Generation Air Transportation System
nm	Nautical mile
NRSP	National Route Structure Plan
OPD	Optimized Profile Descent
PBN	Performance Based Navigation
RECAT	Recategorization
RNAV	Area Navigation
RNP	Required Navigation Performance
RWY	Runway
SCM	Single Center Metering
SID	Standard Instrument Departure
SOIA	Simultaneous Offset Instrument Approach
STAR	Standard Terminal Arrival
STARS	Standard Terminal Automation Replacement System
SUA	Special Use Airspace
TBFM	Time Based Flow Management
TMA	Traffic Management Advisor
TMI	Traffic Management Initiative
TMU	Traffic Management Unit
TOD	Top of Descent

TPA	Terminal Proximity Alert
TRACON	Terminal Radar Approach Control
TWA	Time Weighted Altitude
VHF	Very High Frequency
VMC	Visual Meteorological Condition
VOR	VHF Omnidirectional Range
WITI	Weather Impacted Traffic Index

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